G.E.C. Journal

VOL. I. FEBRUARY, 1931. No. 4.

CONTENTS

	PAGE
FRONTISPIECE: MOTOR COACHES FOR THE BUENOS AIRES TERMINAL CENTRAL RAILWAY - - - -	138
ELECTRICAL PROGRESS AND DEVELOPMENT DURING 1930 - *By H. W. Richardson.*	139
INSULATION FOR 132 kV ELECTRICAL APPARATUS - - *By Charles C. Garrard.*	161
SOME NOTES ON STARTING MOTORS FOR ROTARY CONVERTERS - - - - - - - - *By R. G. Jakeman.*	172
THE MASS PRODUCTION OF INCANDESCENT ELECTRIC LAMPS *By G. Chelioti.*	175
ELECTRIC DRIVES FOR SHIP'S REFRIGERATORS - -	180
THE DESIGN OF HIGH POWER HEAVY OIL ENGINES (*contd.*) *By G. A. Mellor.*	181
INSTALLING OIL-FILLED CABLE - - - - *By R. E. Horley.*	187

Published by

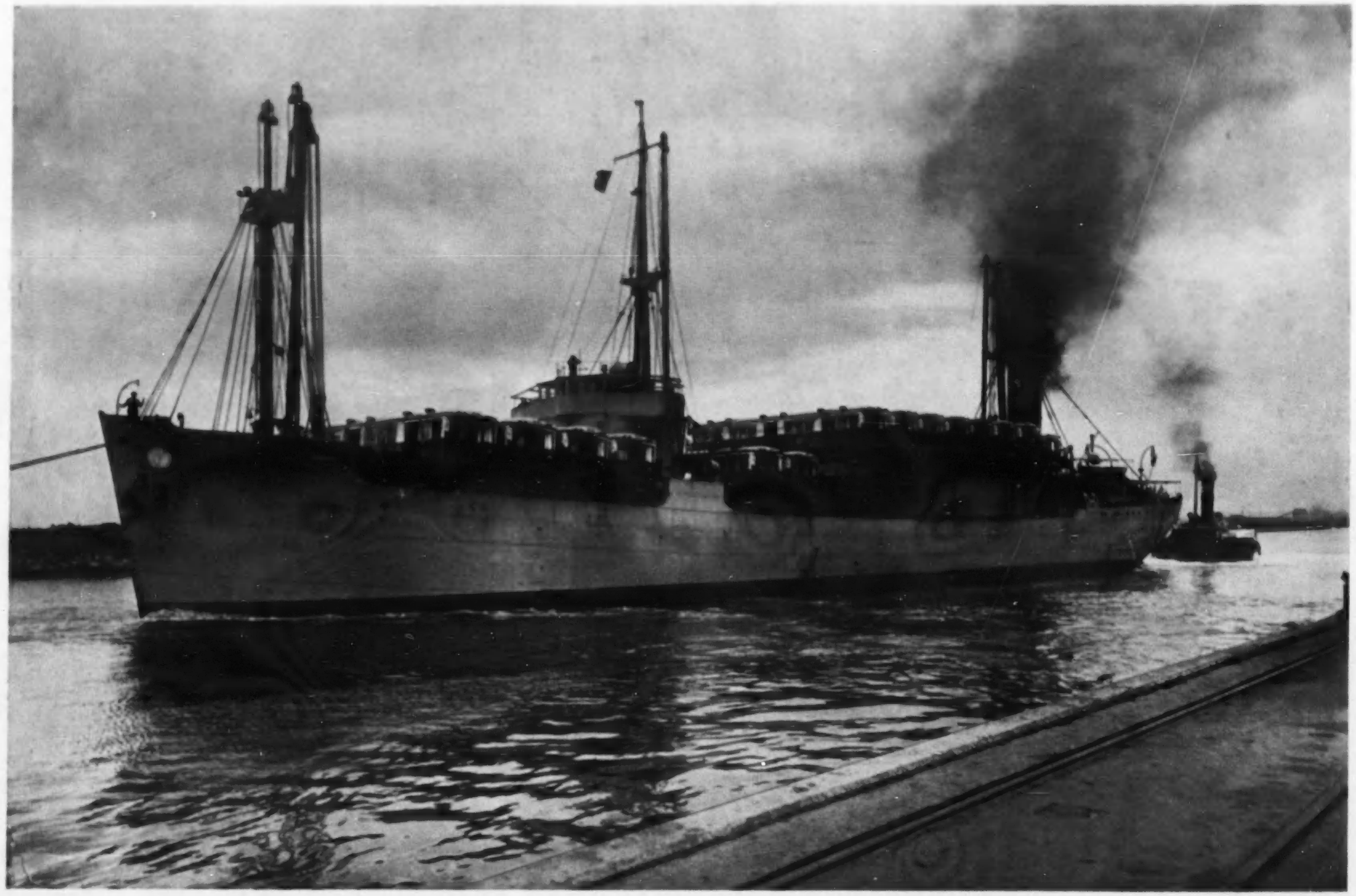
THE GENERAL ELECTRIC Co., LTD.

Magnet House Kingsway London.

COPYRIGHT.

PRICE 1/-

Copies can be obtained from the above address.



G.E.C. ELECTRICALLY EQUIPPED MOTOR COACHES FOR THE ARGENTINE.
Some of the 56 motor coaches constructed in England and electrically equipped by The G.E.C. for the Buenos Aires Terminal Central Railway (see page 151).

G.E.C. Journal

VOL. I. FEBRUARY, 1931. No. 4.

Electrical Progress and Development during 1930.

By H. W. RICHARDSON, B.Sc., A.M.I.E.E., A.M.I.M.E.
Editor of the G.E.C. Journal.

PROGRESS in research and technical development is dependent upon trade cycles only in very minor degree. In a progressive country, the fact that business conditions may be difficult acts as a stimulant, rather than as a deterrent, to further scientific advancement. The pursuit of a consistent policy in regard to the investigation of underlying principles and their application to manufacturing processes, is a far more certain road to economic recovery than the seeking of temporary relief by the curtailment of expense in so vital a matter.

For these reasons it may confidently be affirmed that Electrical Progress in 1930 does not suffer in comparison with that recorded in any of its predecessors, even taking into account those years wherein epoch making discoveries were made. For if there has been no seemingly epoch making event to chronicle during the past twelve months, valuable progress has been made in so many branches of applied electricity that, by a process of integration, the result compares very favourably with individually more spectacular achievements.

Advances which merit special consideration relate to such varied subjects as the introduction of the hot cathode discharge tube into the province of lighting, the development of new alloys for heating elements, the design of a system of telephone call automatic excess fee metering, the commercial production of photo-electric cells, improvements in methods for automatic control, the manufacture of metal clad switchgear of increased capacity, the installation of extra high tension oil-filled cables, and the investigation of high tension phenomena. Problems associated with these subjects and many others of an electrical and mechanical nature have been tackled during the year in the Wembley Research Laboratories, and the Works Development and Technical Departments of the G.E.C. It is the main purpose of this article to indicate the results which have been achieved, attention being directed first to the work of the Research Laboratories.

DISCHARGE LAMPS.

Considerable developments in electric discharge tubes have taken place, as described by Mr. C. C. Paterson in his Presidential address to the Institution of Electrical Engineers (Oct. 1930). It is well known that the light from these tubes results from the passages of an electric current through a rarefied gas. The discharge lamp consists of a glass tube which is bent into any desired form and is fitted with cylindrical iron electrodes at each end. The early forms, developed by Moore in 1893, were filled with nitrogen or carbon dioxide. Since these gases slowly disappear under the action of the discharge, replenishing devices had to be fitted. In 1911 Claude brought out tubes containing the inert rare gas Neon. These need no replenishing as this rare gas does not disappear appreciably, even after running for thousands of hours. When pure, the neon gas gives the well known orange-red colour, and if a small quantity of mercury is introduced, a bright blue colour is obtained. Many new colours have recently been produced by using specially tinted glass and various gas mixtures.

During the last few months a very remarkable new effect has been discovered. This is known

as the "Ripple" type of discharge. In all previous types of tube the luminous glow more or less fills the whole bore of the tube, but in these new tubes the discharge takes the form of a narrow, very luminous cord, the diameter of which is only about one fifth of that of the tube. This cord does not remain stationary along the axis of the tube, but wavers about with a peculiar and fascinating sinuous motion.

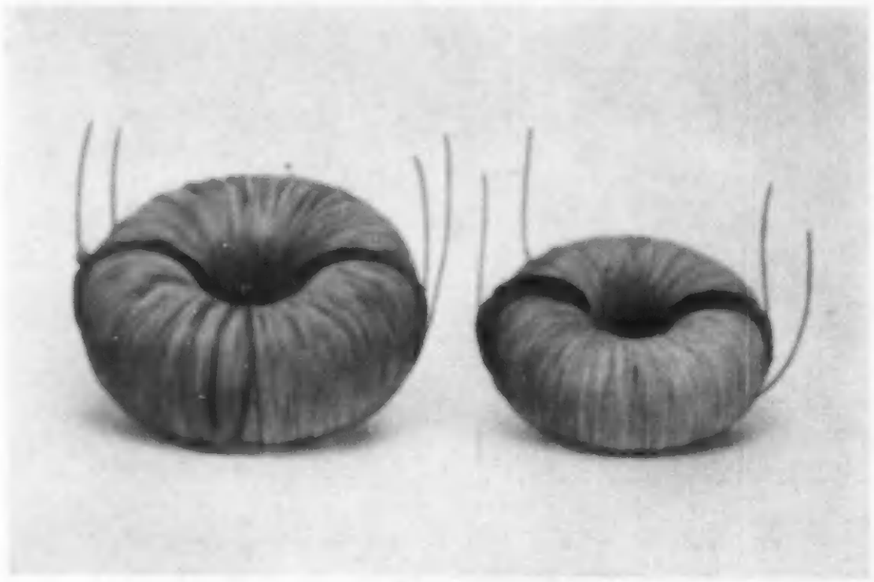


Fig. 1.—Loading coil made with new alloy (small coil), compared with older type (large coil).

All these discharge tubes require a high voltage for their operation and pass a current of 25 to 150 milliamperes. Another new development is the introduction of a low voltage type which runs direct on ordinary supply voltages and takes from 1 to 6 amperes. This is known as the hot cathode type and its efficiency is higher than the ordinary cold cathode type. The hot cathode tube which is most efficient of all, contains sodium and is more than twice as efficient as an incandescent filament lamp.

LOADING COILS FOR TELEPHONE CABLES.

Great improvements in loading coils for telephone cables have been effected during the past year and the coils now being made for the British Post Office and other users, are wound on cores of a material to which the name "Gecalloy" has been given. The cores are made by a process developed at Wembley which involves new methods of manufacture of nickel-iron alloy powder and improved methods of insulating the particles so obtained.

A requirement of a loading coil is that it shall have an extremely constant inductance in spite of such destructive influences as the heavy currents which may be caused by faults in power installations adjacent to the telephone line. It is also necessary that it should have a very low ratio of effective resistance to inductance, and—directly conflicting with this requirement—as small a size as possible, since hundreds of coils may need to be installed in a small street manhole.

These requirements have been met in the past up to a certain point by the use of fine iron dust, insulated and compressed to pressures up to, and beyond, the elastic limit. In this way cores with a permeability of 20 to 35 have been obtained. It has been apparent, however, that the increasing demand for higher quality transmission over long distance telephone lines could no longer be met by such coils, and attention has therefore been turned to the improvements which might be expected to result from the use of nickel iron alloys. The difficulties encountered in perfecting the new design were considerable.

In order to obtain low eddy current losses and to ensure stability, fine particles, adequately insulated from one another and then compressed to a solid mass, must be used. As the magnetic properties of the nickel irons are impaired by mechanical strain imposed by the very high pressures used, it is necessary, as a final process, to submit the cores to a high temperature heat treatment. The insulation, therefore, must be able to withstand this temperature. A further difficulty arises in that the nickel-iron alloys are comparatively ductile, and much work has been necessary in order to discover a commercially practicable process for making the alloys in fine powder form. These difficulties have been overcome and the process is now carried out on a quantity production scale.

Some idea of the improvement effected will be obtained from fig. 1, which shows the relative sizes of the old and new coils. Permeabilities of 40 to 100 are practicable and, in addition to the improvement in size, a new coil such as that illustrated in fig. 1 has an effective resistance about 10 per cent lower than the old. It is also much more stable, the inductance changing by less than 1 per cent, as against 2½ per cent when the coil has been submitted to a direct current of 2 amperes. A further improvement attributable to the use of the new powder lies in the reduced hysteresis factor. The hysteresis loss

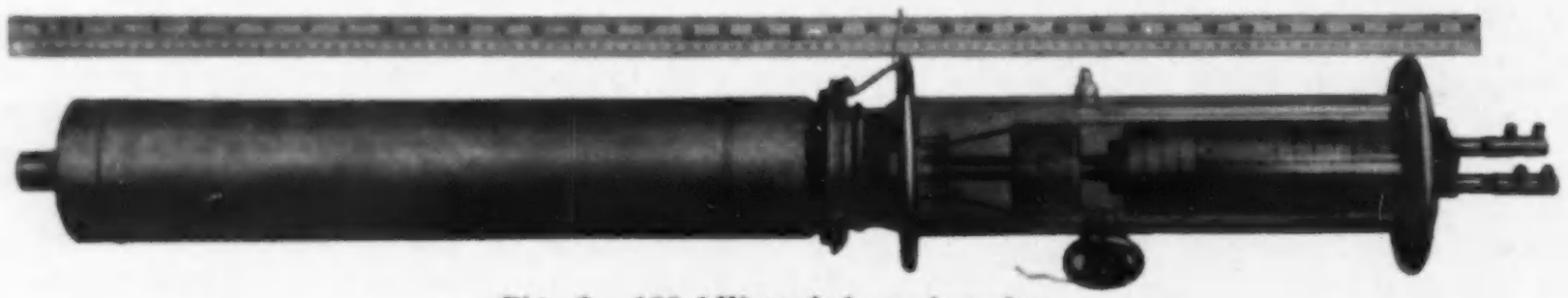


Fig. 2.—100 kW cooled anode valve.

of the coils affects their operation by causing an increased effective resistance proportional to the current. In the case of a long telephone line with many coils, this may cause non-linear distortion of speech currents and cross modulation from superimposed telegraph currents.

If required, the new coils can be designed to give up to 50 per cent. improvement in freedom from hysteresis effect on equivalent sizes of the old coils.

ILLUMINATION.

A new range of pressed glass reflectors for exterior flood-lighting has been designed, and for the lighting of corridors or places with little head-room, such as coal mines, a prismatic front glass for a bulkhead type of fitting has been developed.

Existing street lighting apparatus has also been improved, and a new type of fitting consisting of a combined reflector and refractor has been introduced, while the non-ventilation of lanterns up to 1,500 watts has been standardized.

Heat absorbing glasses have been studied with a view to their use in cinema studios, and it has been found possible by the process already used for ordinary glasses to treat these so as to render them diffusing. In this same connection an extensive study has been made of the relation between the intensity of illumination and the temperature of a standard receiver placed in the beam.

The design of the Class A.1 tubular projection lamp has been improved to give increased efficiency.

NEW ALLOYS.

New types of nickel-chromium alloys for heating elements have now reached the stage of commercial production. The most important new feature in this connection is the development of a process by which such alloys can be melted in hydrogen and then cast in air while retaining the properties peculiar to hydrogen-melted metals. Improvements in the composition of these wires have also been made, resulting in an increased life of the heating elements.

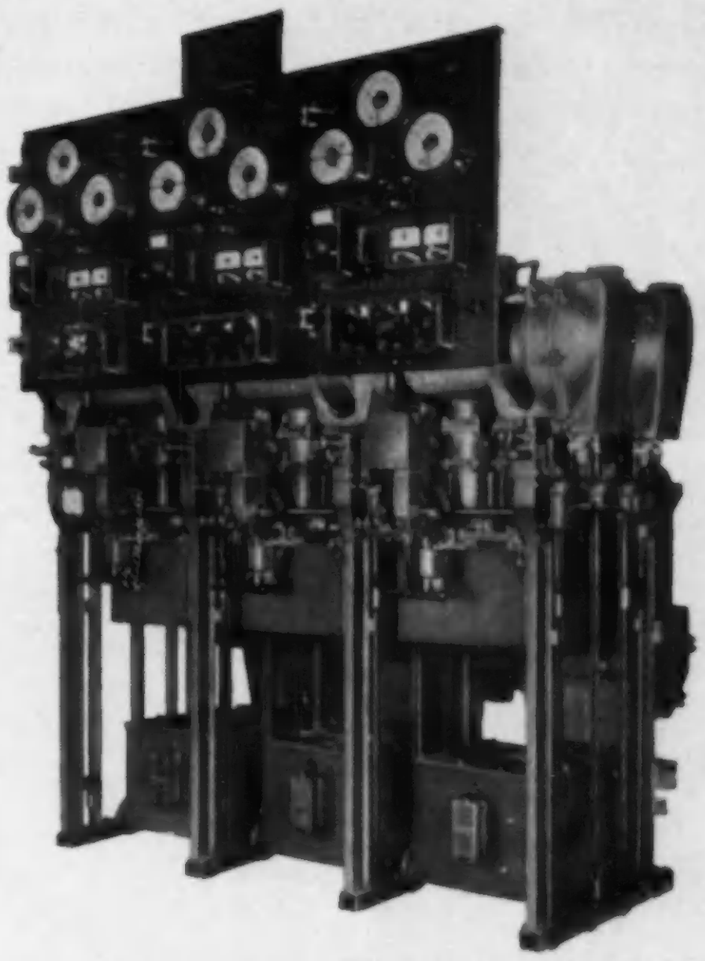


Fig. 4.—Typical of the smaller units—a 150,000 kVA, 11 kV metal clad switchboard.

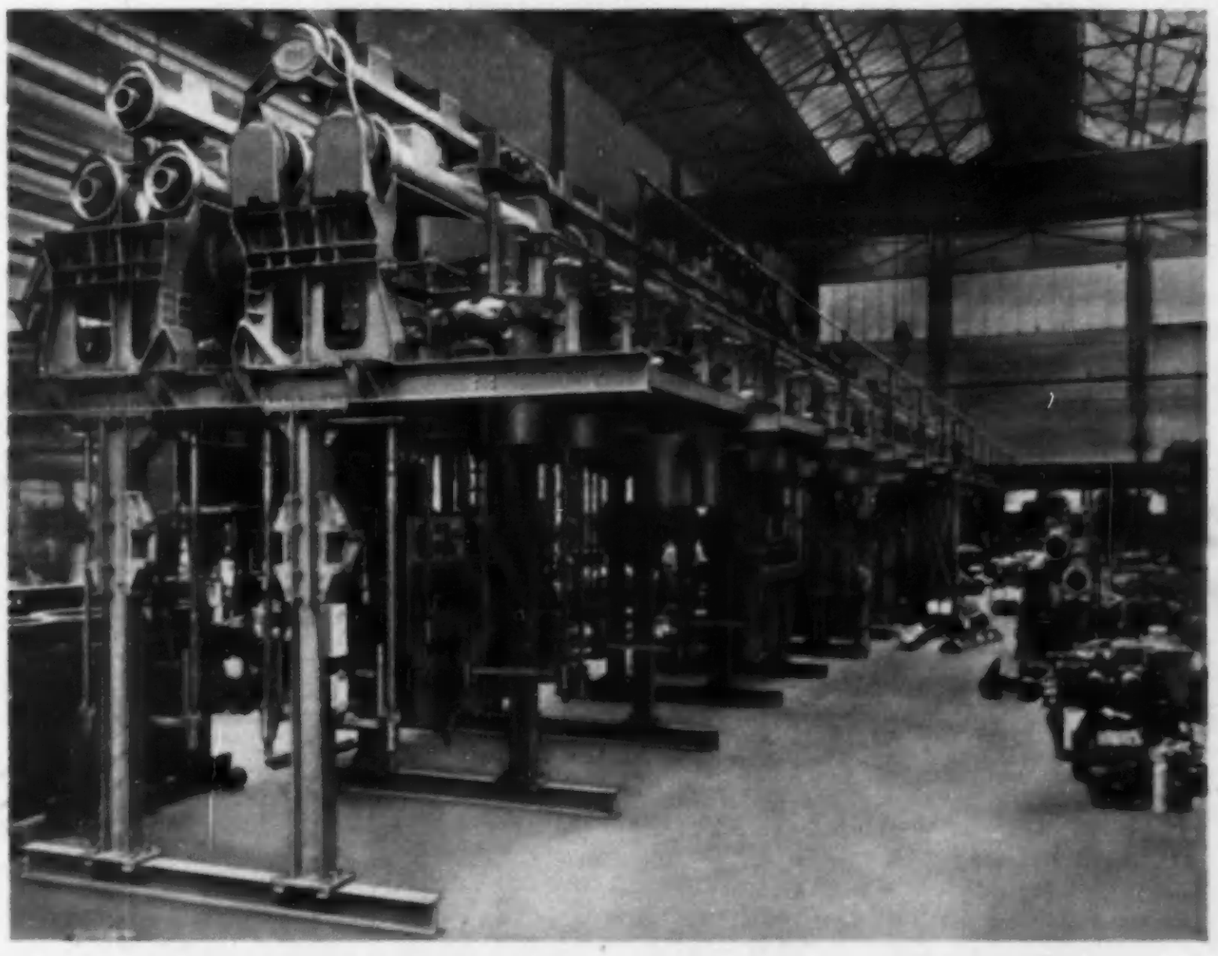


Fig. 3.—Part of a 1,000,000 kVA, 22 kV metal clad switchboard under construction.

PHOTO-CELLS.

The principal work in connection with the making of photo-cells has been the investigation of the problems arising from the introduction of caesium cells into commercial production. There has been a considerable demand for them in the talking film industry. A great deal of work has been carried out on the "time lag" and frequency characteristics of these cells.

GLASS AND REFRACTORIES.

Glasses of very special and peculiar composition have been made for the newly developed sodium vapour discharge lamps, in addition to new types of coloured tubing for neon signs.

A new slip-casting technique has been developed for making crucibles from pure highly refractory oxides completely free from bonding materials, the presence of which affects the refractoriness. Progress has also been made in the method of removing iron from ceramic materials by mixtures of various gases, while improvements have been effected in refractories in the direction of permanence of dimensions and resistance to corrosion by molten glass.

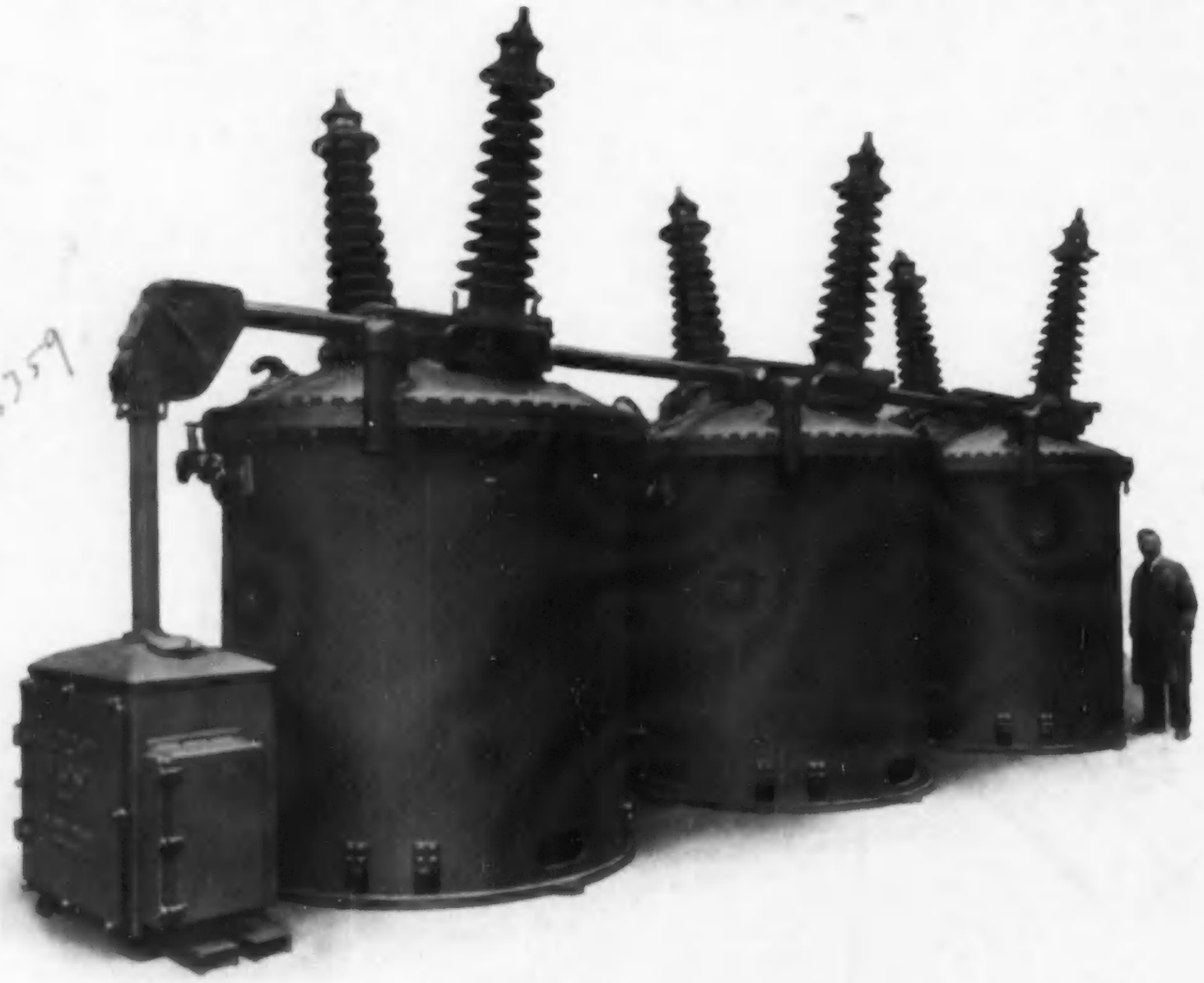


Fig. 5.—One of the eighty 1,500,000 kVA, 132 kV outdoor 3-phase oil circuit breakers for the British "Grid."

DOMESTIC APPLIANCES.

The conditions affecting the life of withdrawable type immersion heaters have been studied, and as a result of the investigation modifications have been made in the design of both the heaters themselves and the sockets in which they are fitted. These changes have led to a very considerable reduction in wire temperature and have resulted in a corresponding increase in life.

The design of connectors for domestic irons and other appliances has received attention and the standard connector has been greatly improved by the fitting of a new and very effective cord grip of a novel type.

COOLED ANODE VALVES.

There has been a big advance in the size of cooled-anode valves. A valve has recently been constructed for use as an oscillator, which is capable of handling 100 kW input (fig. 2).

This has been tested to 50—60 kW dead loss, and has withstood a test voltage of 20,000. There are three filaments in parallel, each taking 75 amps. at 30 volts, the normal emission being 35 amps. The filament leads are water cooled to dissipate heat conducted from the filament and generated in the leads themselves. The normal emission is 35 amps. The anode is 4 ins. in diameter and 20 ins. long, and the total weight of the valve is 18 lbs.

SWITCH AND CONTROL GEAR.

The development in switch and control gear is perhaps best measured by the increased voltages and current carrying capacities of the apparatus manufactured and in course of construction in Witton Switchgear Works. Reference was made in the first article in the *G.E.C. Journal*, "Electrical Progress in 1929," to the erection of metalclad switchgear of 1,000,000 kVA breaking capacity (fig. 3). This type of gear is now in hand with a breaking capacity of 1,500,000 kVA. Corresponding development is taking place in switchgear for outdoor purposes as required by the British Grid and similar transmission systems (fig. 5). The successful design and testing of such control gear is closely

linked with the work of the High Tension Laboratory at Witton, which is one of the foremost laboratories of its kind in the world. As it is described in a subsequent article in this issue further reference here is unnecessary.

Automatic control is being adopted more and more widely. Its application to power supply sub-stations and industrial electrification in general has been noteworthy. A very high degree of reliability in operation is obtainable, and the design of new relays and improvement in existing types has contributed largely to this end.

METALCLAD SWITCHGEAR.

An important improvement has been introduced into the design of the hoist gear employed for metal-clad breakers. It is the subject of G.E.C. Patents. The actual raising and lowering of the breaker is by means of steel screws which are hand operated in small sizes and motor operated in larger sizes. The nut blocks actuated by the screws engage with lugs mounted on the sides of the breaker tank. The new feature embodied is the method of coupling to the driving gear. The coupling consists of a universal joint which enables the screw to swing freely when disengaged from the breaker. By this means rails or similar expedients to ensure accurate alignment of the breaker transfer

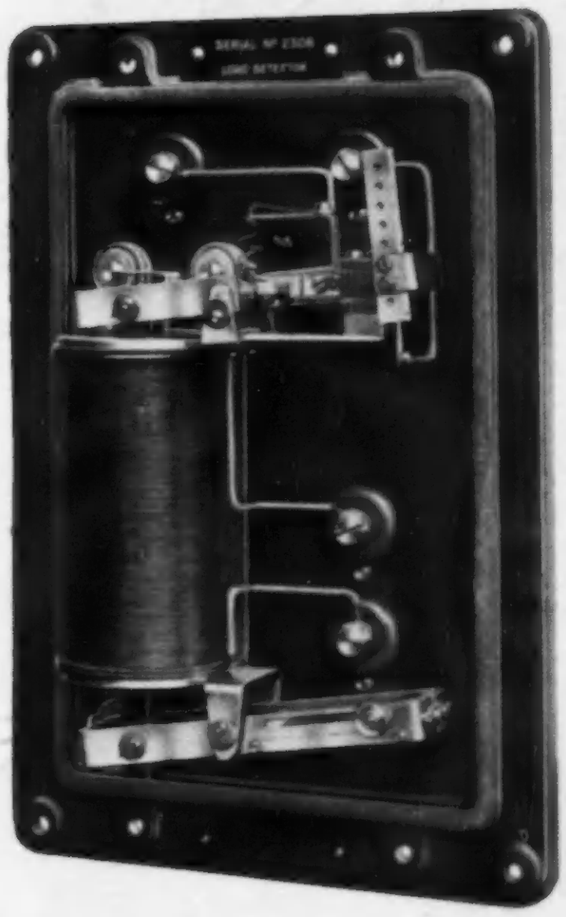


Fig 6.—Load detector relay, cover removed.

truck are abolished, as wherever the switch is placed when under the unit the screws, which carry the nut blocks, can be swung to engage with the breaker tank and from this position the breaker is raised. Immediately the breaker leaves the truck it will automatically swing to its correct position.

AUTOMATIC CONTROL EQUIPMENTS.

The foregoing general remarks upon the automatic control of sub-stations apply particularly to sub-stations of large capacity, as illustrated by the Broad Street sub-station of the Charing Cross

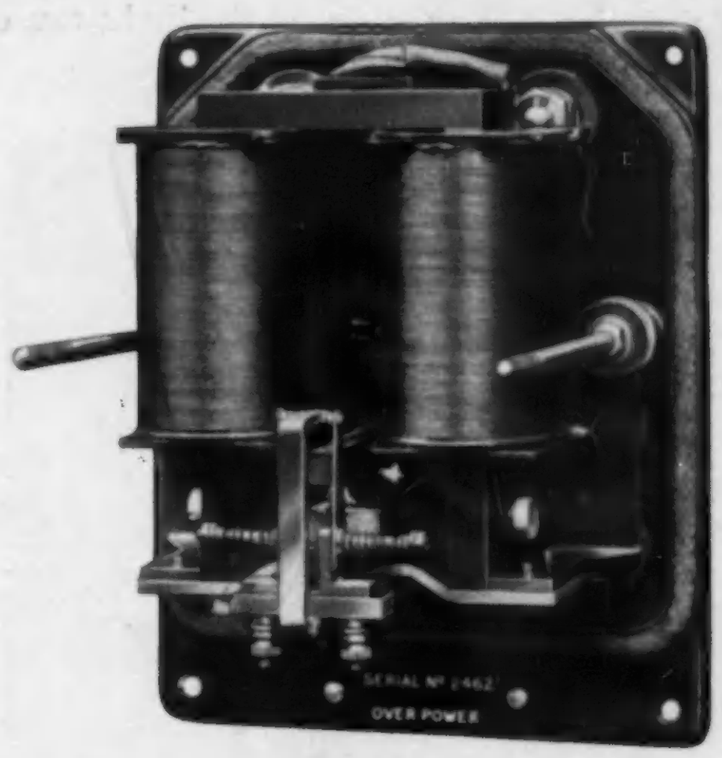


Fig. 7.—Over-and-reverse-power relay, cover removed.

Electricity Co., in which two 2,000 kW motor converters are being erected, while eventually two further units of this output will be installed. Another example is furnished by the Arlington Road sub-station, St. Pancras, which will contain three 2,500 kW motor converters for automatic operation.

A typical scheme of automatic control for industrial purposes, is that for the operation of two large electric winders recently built for an Australian mining company. The Ward Leonard principle is employed and the functions of the machines are controlled by a motor operated controller, the motor being push button operated. "Up" and "down" and "stop" push buttons are situated in the main control room, at the pit bank and at three levels of the mine, control being transferred to the required station by means of a master switch.

Amongst new relays for use in automatic equipments the load detector relay (fig. 6) possesses features of interest. It has been developed to control the reclosing of stub-end traction feeders, according to the resistance of the external circuit. It is based upon the well known principle of passing a small current through the load and measuring the volt drop in the load circuit. The extreme sensitivity obtainable is indicated by the fact that definite discrimination is obtained by allowing a test current of only one thousandth of the value of the setting to flow in the external circuit. Perfectly accurate operation has been given after long periods of inaction.

Another novel type of relay is an A.C. low voltage relay which introduces a new method of producing a rotating torque on an aluminium (or copper) disc, when the element is energised by a single phase supply. The magnetic system consists of a three limb laminated core mounted above the rim of the relay disc. On one of the limbs two coils

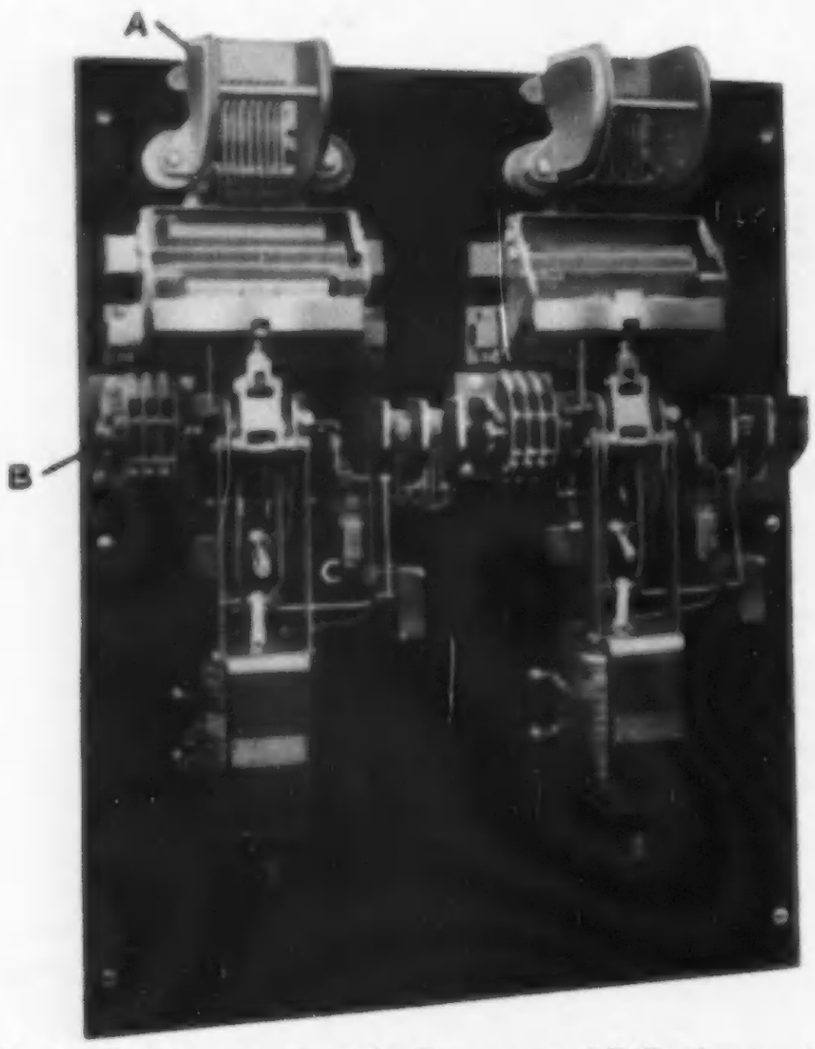


Fig. 8.—5,000 amp. electrically operated D.P. line contact circuit breaker with magnetic blowouts (A), auxiliary circuit switches (B), and time lags (C).

are wound, the first being connected to the single phase supply while the second forms a closed circuit with a third coil wound on the other limb. Induced currents flow in the second and third coils and when the iron and copper circuits are suitably proportioned, the three coils together produce a rotating magnetic field closely approximating to the field which would be formed if a three phase exciting supply were used. This causes a much more even torque on the relay disc and in consequence makes for a more robust and reliable relay than would be the case if the more common arrangement of single coil and copper shading ring were used.

PROTECTIVE GEAR.

Progress in relay design is also reflected in the many control schemes which have been prepared for marine installations. Considerable success has been achieved by remote control relays working on the Wheatstone bridge principle, also by over-and-reverse-power relays (fig. 7) employing the D'Arsonval methods. The strength of mechanical construction which is so necessary for relays on ships has in no way interfered with the attainment of high sensitivity.

Two of the new marine relays are for the purpose of safeguarding motors and generators against the effects of insulation breakdown. The first of these resembling those just described is for the protection of D.C. machines on the balanced voltage principle, while the second, for the protection of A.C. machines, consists of a Ferraris disc equivalent of the biassed beam relay, employed in the G.E.C. Protective system based on McColl patents.

Apart from special applications there has been a general extension in the use of protective gear. For example, it has been applied to nine feeders including single step-up power transformers, while methods have been devised for protecting small auto-transformers with bar primary current transformers. Another point of interest is the new type of relay with flag indicator to show which unit has tripped, a refinement now incorporated in this class of apparatus as standard.

The parallel interconnector scheme for feeders (described in W. Wilson's article, "Balanced Protection of High Tension Parallel Interconnectors," *G.E.C. Journal*, Vol. 1, No. 1), has been installed with successful results in three important centres during the year. In another instance, to meet special requirements, it was developed in double acting form. The need for reducing the cost of apparatus employed for rural distribution, led to the introduction of two pilot feeder protective schemes, which seem likely to be adopted for many purposes.

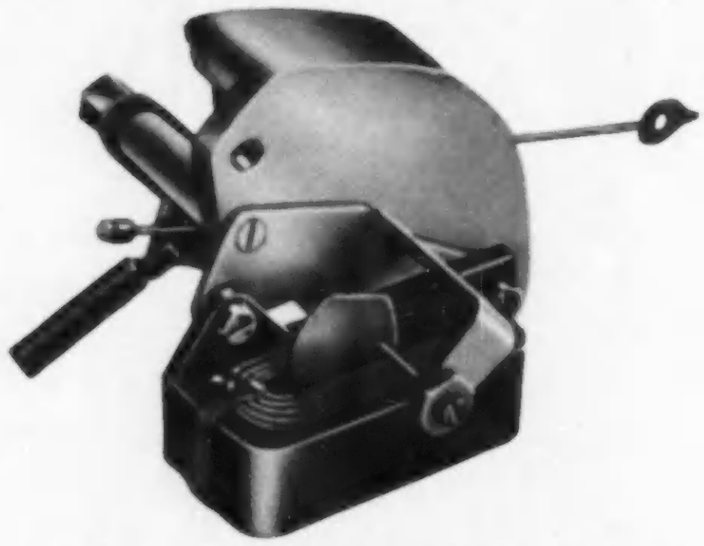


Fig. 9.—Detail view of movement of low volt-ampere consumption instrument.

Owing to the difficulty of calculating the distribution of fault currents in large and complicated networks, a convenient form of artificial network apparatus has been developed, whereby the distribution not only of balanced three-phase faults, but also—if desired—of faults to earth, can be ascertained by the simple operation of dials on panels representing the various elements of the circuit.

LINE CONTACT SWITCHGEAR.

The further study of the principles of line contact switchgear (see "The Line Contact Air Break Circuit Breaker," by A. Sherwin, *G.E.C. Journal*, Vol. 1, No. 2) has resulted in sizes of considerably increased capacity. A line contact air circuit breaker for 10,000 ampere circuits is now available. Improvements in design have been effected by the introduction of magnetic blowouts, also by a new form of automatic switch for making and breaking auxiliary contacts; further, the no-volt and shunt tripping devices are now of a solenoid self re-setting pattern.

One model presenting features of interest is a 1,500 amp. double-pole circuit breaker in which the V contacts are held closed by means of compression springs, and caused to open by a direct force on these springs produced by operating solenoids. The latter are mounted upon trunnions, and thus operate with an oscillating motion. This novel arrangement avoids the usual problems of angularity in an effective manner.

An illustration of a 5,000 amp. double pole breaker with time lags and auxiliary switches is shown in fig. 8.

Another adaptation of the line contact method takes the form of a 1,000 ampere marine isolating switch suitable for use in confined spaces.

CLOCK-WORK TIME LAGS.

It is well known that oil dashpots, whilst of value for many purposes, are not suitable for widely varying conditions of climate. For this reason a clockwork time lag has been successfully developed, good results having been obtained particularly in connection with marine work. Four forms are available, three being for large A.C. motors, large D.C. motors, and small motors, while the fourth is an individual type which is applied to each accelerating contact of any capacity.

NEON VALVE EARTHING DEVICE.

A new type of earthing device has been produced and supplied in quantity for protecting the structures, etc., of railway sub-stations. The device depends for its action upon the operation of a neon valve of high current capacity which becomes conductive at about 160 volts. It is capable of carrying 3,000 amperes for three minutes without overheating.

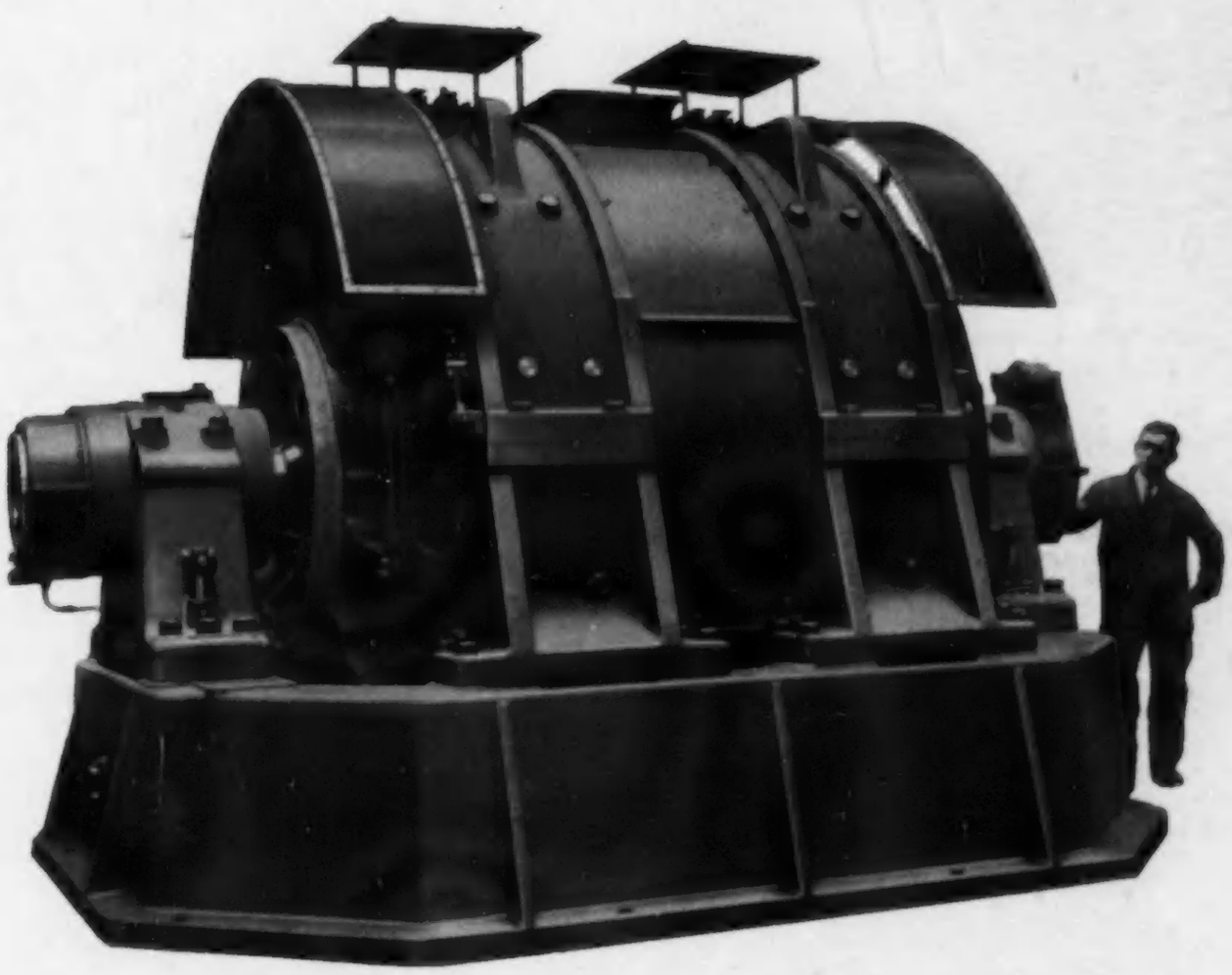


Fig. 10.—775 h.p. Double armature D.C. ship propulsion motor built for the E.M.V. "Cementkarrier." (See page 146).

LOW VOLT-AMPERE CONSUMPTION INSTRUMENTS.

The use of "bushing" or "slip-on" type instrument transformers in high tension installations of relatively small current capacity makes necessary an indicating instrument of low volt-ampere consumption. Such an instrument, embodying many ingenious features designed to reduce losses to a minimum, has recently been designed (fig. 9), and tests made upon it show thoroughly satisfactory results. The instrument is of the attraction type, with an eccentrically placed disc of a nickel alloy which tends to rotate about and with the shaft carrying the pointer. It is drawn into an elliptically

shaped coil. This construction brings the winding very close to the disc and by reducing the mean length of turn, decreases the resistance and inductance but increases the forces attracting the disc. As the current through the coil is increased and more of the disc enters the coil, the scale tends to close rapidly towards the top, but careful shaping of the disc has ensured a satisfactory scale.

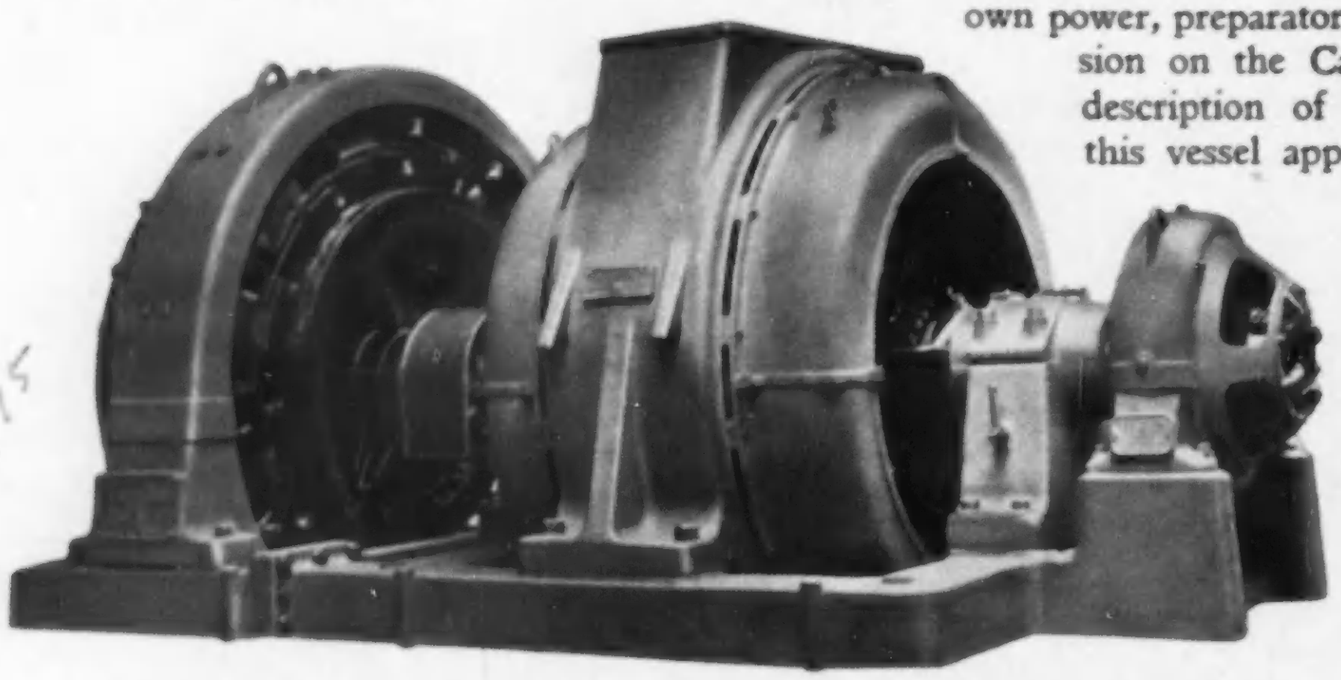


Fig. 11.—600 kW motor-generator, comprising 13,200 volt synchronous induction motor and 120 volt D.C. generator, supplied to a film studio.

It is interesting to compare the consumption of this instrument with that of the standard moving iron pattern of a similar size, both instruments being wound for full scale deflection with 0.5 amperes. The former instrument had a consumption of 0.41 and the latter of 1.55 volt-amperes. Both instruments had the same length of pointer but the latter instrument had an angular deflection of 105° against the former instrument's angular deflection of 90°.

It was found that the difference in reading between an ammeter of this new type calibrated for use on 50 periods per second and its reading on direct current was extremely small, coming within the limits specified by the British Engineering Standard Association specification No. 89/1929 for first grade ammeters.

POWER PLANT.

Though control gear seems to monopolise a large share of the interest of electrical engineers at the present time, electrical power units are being steadily developed and progress has occurred in several directions. One of these relates to marine electrification. During the year an all-electric self discharging vessel was laid down in this country (the E.M.V. "Cementkarrier"), and a few months ago crossed the Atlantic under her own power, preparatory to being placed in commission on the Canadian Great Lakes. A full description of the electrical equipment of this vessel appeared in the last issue of the *G.E.C. Journal* (Vol. 1, No. 3). Further machinery for the electric propulsion of ships is now in course of construction in Witton Works, of which full information will be published later.

The improvement in materials used in turbo alternator construction has resulted in the building of a turbo alternator with output of 37,500 kVA at a speed of 3,000 r.p.m. Very few machines of so large an output have yet been built to run at this speed, and tests made upon it have given entirely satisfactory results.

Extensions to Birmingham Corporation Power Stations involve the building of two further large sets, that for the Nechells station having an output of 30,000 kVA at 3,000 r.p.m., while the Hams Hall machine is rated at 37,500 kVA for a speed of 1,500 r.p.m.

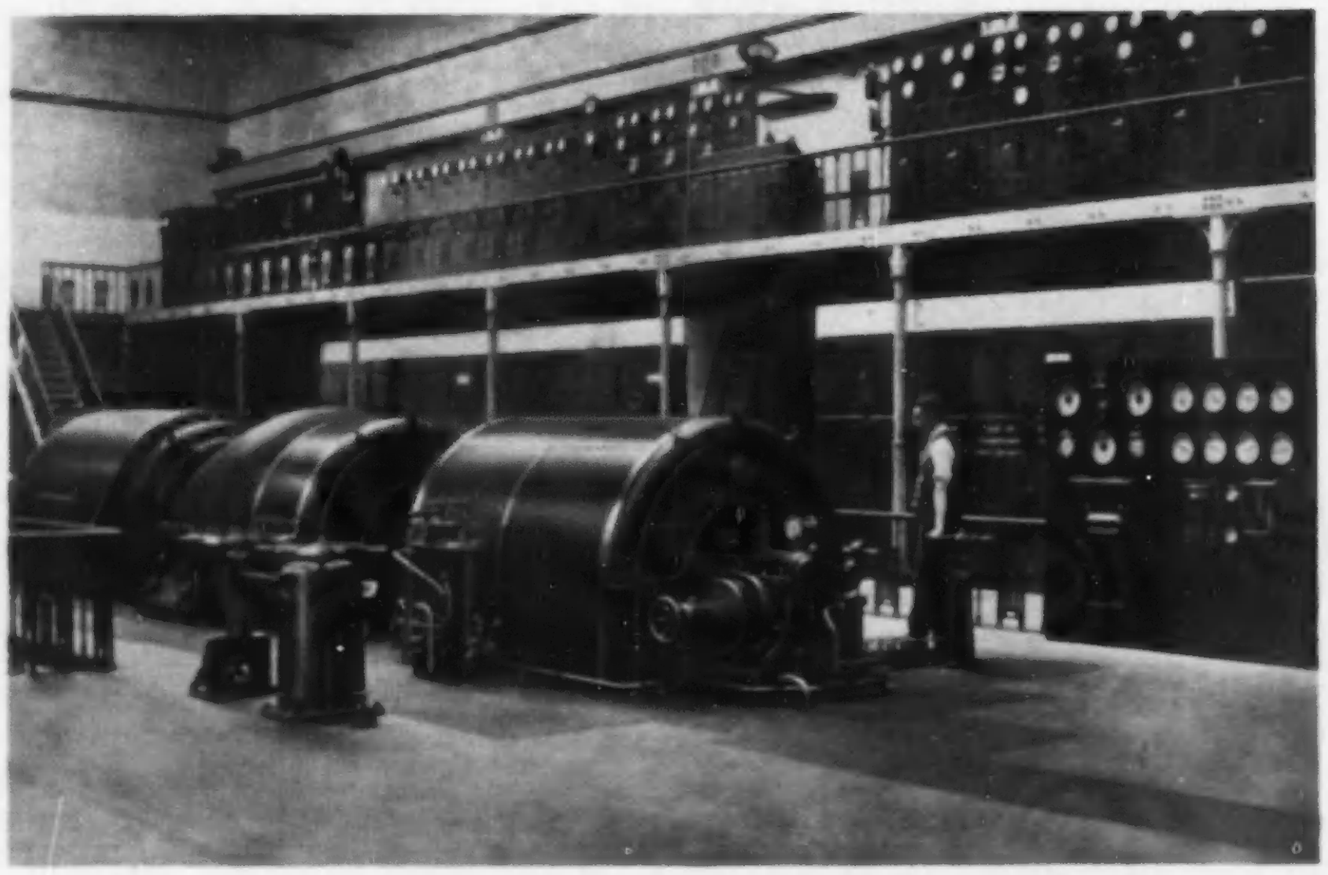


Fig. 12.—A 10,000 kW 3,000 r.p.m. double pass-out turbo alternator, the largest of its type in Great Britain installed for supplying the extensive paper mills of Edward Lloyd & Sons, Kent.

Many units with interesting features have been designed for use in the "Talkie" industry, one

example which may be cited being a synchronous motor generator set (fig. 11) of which the motor operates on a 13,200 volt, 50 cycle circuit while the direct current generator supplies a 5,000 ampere current. Rotary converters for traction service abroad have been built with 1,000 volts on a single commutator.

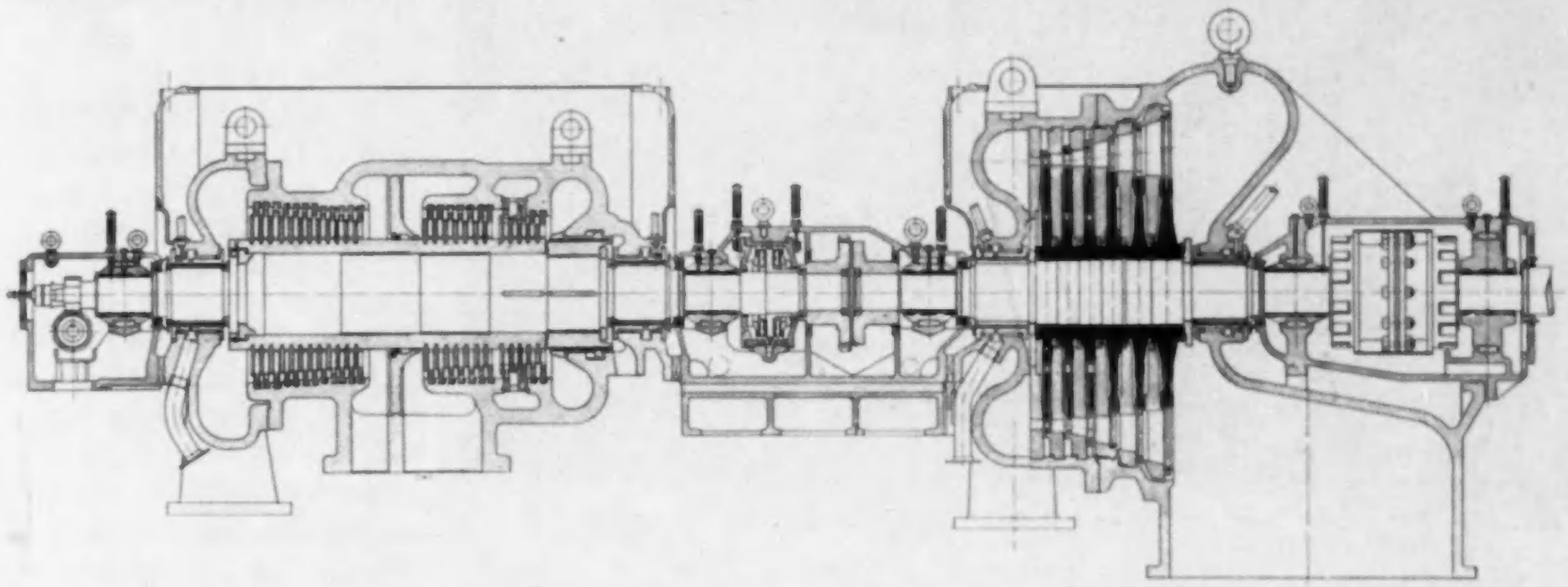


Fig. 13.—Sectional elevation of the 10,000 kW set shown in fig. 12.

As a result of the decision of the Electricity Commissioners to standardize frequency, a large number of frequency changers have been built. Rotary converters are now available which will operate on 40 or 50 cycle circuits, or on 25 or 50 cycle circuits.

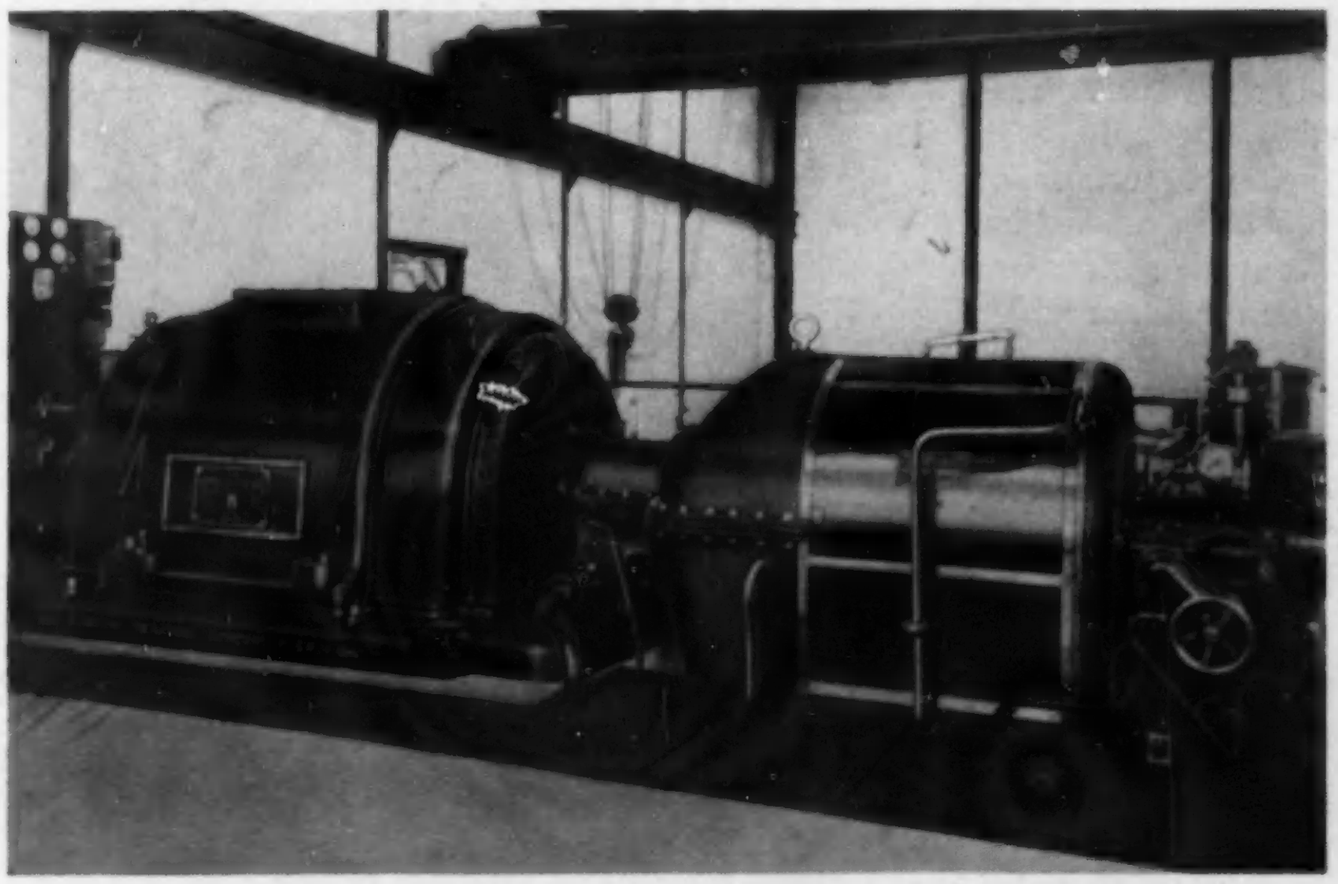


Fig. 14.—A combined pass-out and back-pressure turbo-alternator of 5,000 kW, 3,600 r.p.m.

TURBINES.

Steam turbine development has continued to show two marked tendencies. The first is towards central station units of ever increasing capacity at lower cost per kW with better heat economy. The second affects the industrial market which is taking greater advantage of combined power and heat supply as afforded by back pressure and passout turbines.

An excellent example of a turbine driving an electricity generator and providing steam for heating purposes is afforded by a 10,000 kW, 3,000 r.p.m. unit in a paper mill, which is the largest yet built in this country (figs. 12 and 13). Of a specialised nature is a combined pass-out and back-pressure turbine of 5,000 kW output running at 3,600 r.p.m. (fig. 14). It consists of one velocity wheel with two rows of blades and five single stages. At its maximum output it receives 130,000 lbs. of steam per hour at a pressure of 375 lbs./sq. in. and a temperature of 543° F. For heating purposes, 25,000 lbs. of steam per hour is bled at a pressure which is maintained practically constant at 150 lbs. per sq. in. After the rest of the steam has passed through the remaining stages it is exhausted into a heating main at 15 lbs. per sq. in. This pressure is maintained constant by means of a constant pressure governor which is inter-connected with the valves controlling the steam quantity at the inlet of the turbine. In case there is a tendency in the second heating steam main for the steam pressure to fall, the constant pressure governor actuates the inlet control valves opening them more, so that more steam is admitted to the turbine and the desired

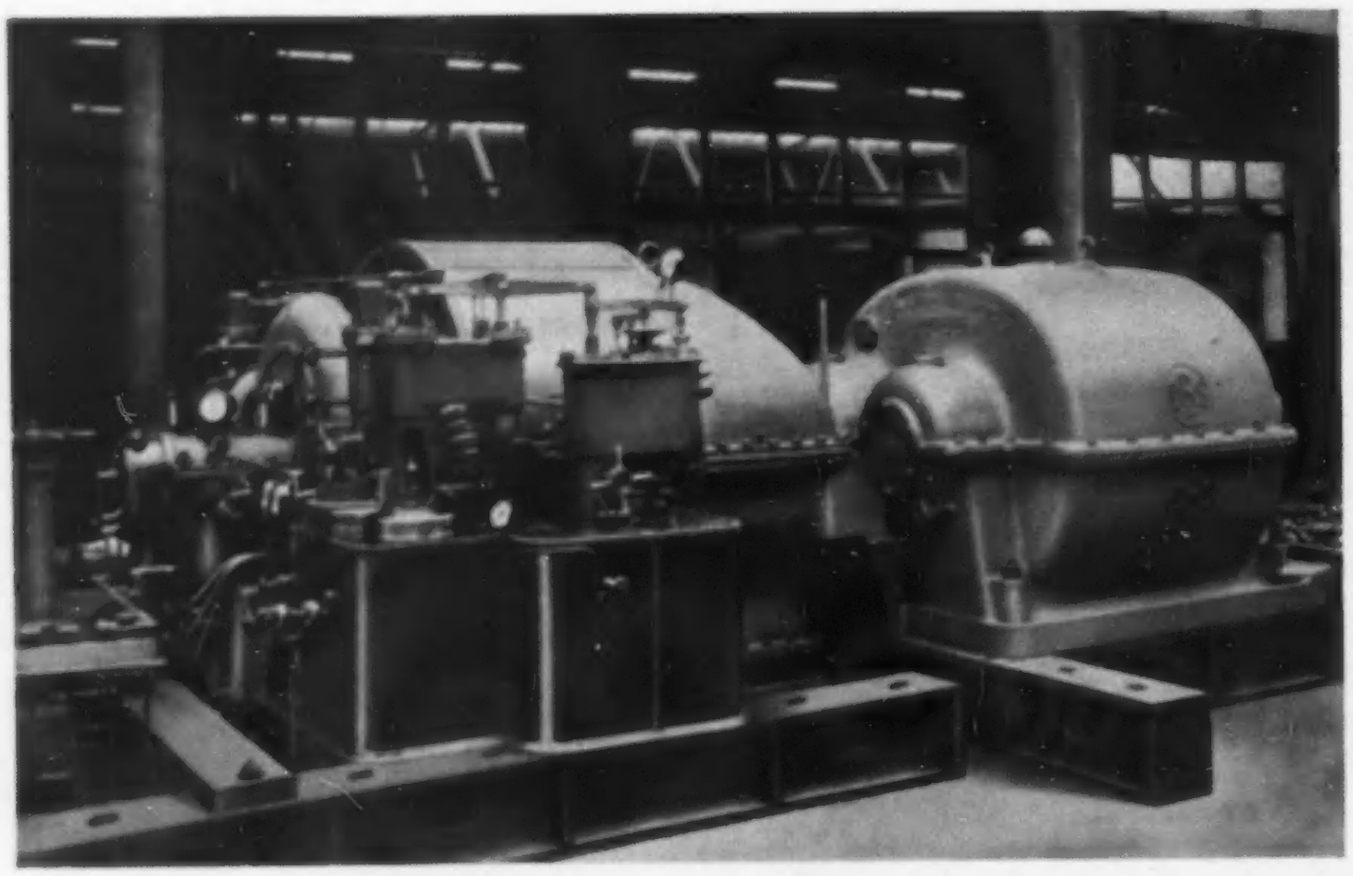


Fig. 15.—For paper mill service—a 5,000 kW, 3,600 r.p.m. geared turbine on test.

steam pressure in the second heating steam main is restored; the output increases at the same time but as this machine is coupled on the electrical side with other sets, the latter automatically reduce their output. Special provision is made for operating this set alone. For that purpose the constant pressure governor in the second heating steam main is cut out of action and simultaneously a speed governor, which otherwise acts only as a speed limiting device, is brought into action by means of a speeder gear operated by oil under pressure. This machine is therefore noteworthy, not only as a combined pass-out and back-pressure turbine of quite considerable output, but also as a machine which operates either under the control of the steam pressure in the second heating steam main, or under the control of a speed governor.

An application of turbine drive for a water pumping station should be mentioned. Four sets are now under construction, each of normal capacity approximating to 1,500 h.p. at 5,700 r.p.m. The steam pressure is 250 lbs. per sq. in. with superheat 175°F. and vacuum 28.5 in. Two of the turbines are each geared to a main centrifugal pump and a booster centrifugal pump coupled by a clutch to the shaft of the main pump. The other two turbines are each geared to a main centrifugal pump and booster centrifugal pump coupled in the same way, while in addition a 200 kW D.C. generator is coupled by a clutch to the booster pump shaft.

GEARED TURBINES.

The use of geared turbines is increasing. The outputs of such sets are larger than previously, a recent geared pass-out turbine of 5,000 kW having recently been installed for paper mill service (fig. 15). Its speed is 3,600 r.p.m., and it drives two 2,500 kW generators in tandem at 500 r.p.m. A maximum of 60,000 lbs. of steam per hour is supplied for heating purposes at a pressure of 15 lbs. per sq. in.

A noteworthy development in the arrangement of small and medium size sets of this type is a combined set, the condenser body being combined with the lower half of the turbine exhaust. The height of the set is thus substantially reduced so that the whole set can be mounted on the engine room floor; the cost of foundations is reduced and the attendance is simplified.

This type of machine is built as a high pressure, pass-out, or mixed pressure turbine.

TURBO-BLOWERS.

A new application of turbine blowers is for gas compression. In a unit recently built, the gas volume at the inlet is 43,000 cu. ft./min. the pressure being 14.7 lbs. sq. in. abs., temperature 185°F. and the specific gravity of the gas .04 lbs./cu. ft. The delivery pressure is 19.1 lbs./sq. in. abs. The blower is built as a 3-stage double flow machine.

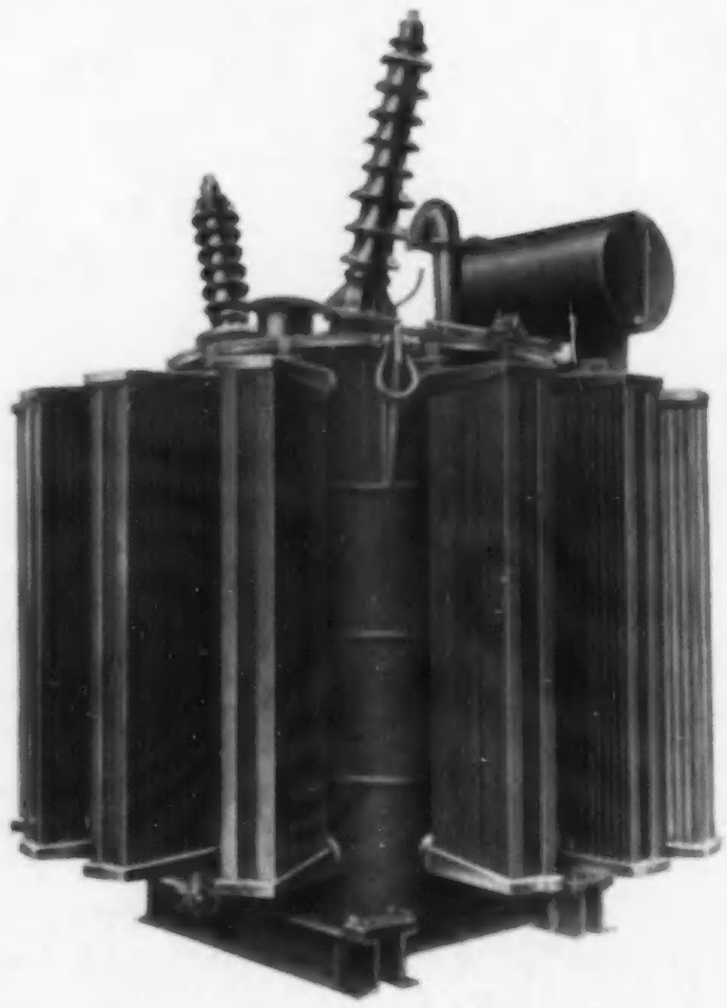


Fig. 16.—One of seven 5,500 kVA, 110/66/11 kV single phase transformers for Waitaki Power Board, New Zealand.

The glands are of the labyrinth type and in order to prevent gas leaking to atmosphere or air leaking into the gas, the main glands are arranged for steam sealing. The turbine driving this blower consists of a velocity wheel with two rows of blades and 15 single stages of small diameter, drum type design for these stages being used. It operates with a steam pressure of 250 lbs./sq. in. steam temperature 500°F. and a back-pressure of 15-lbs./sq. in.

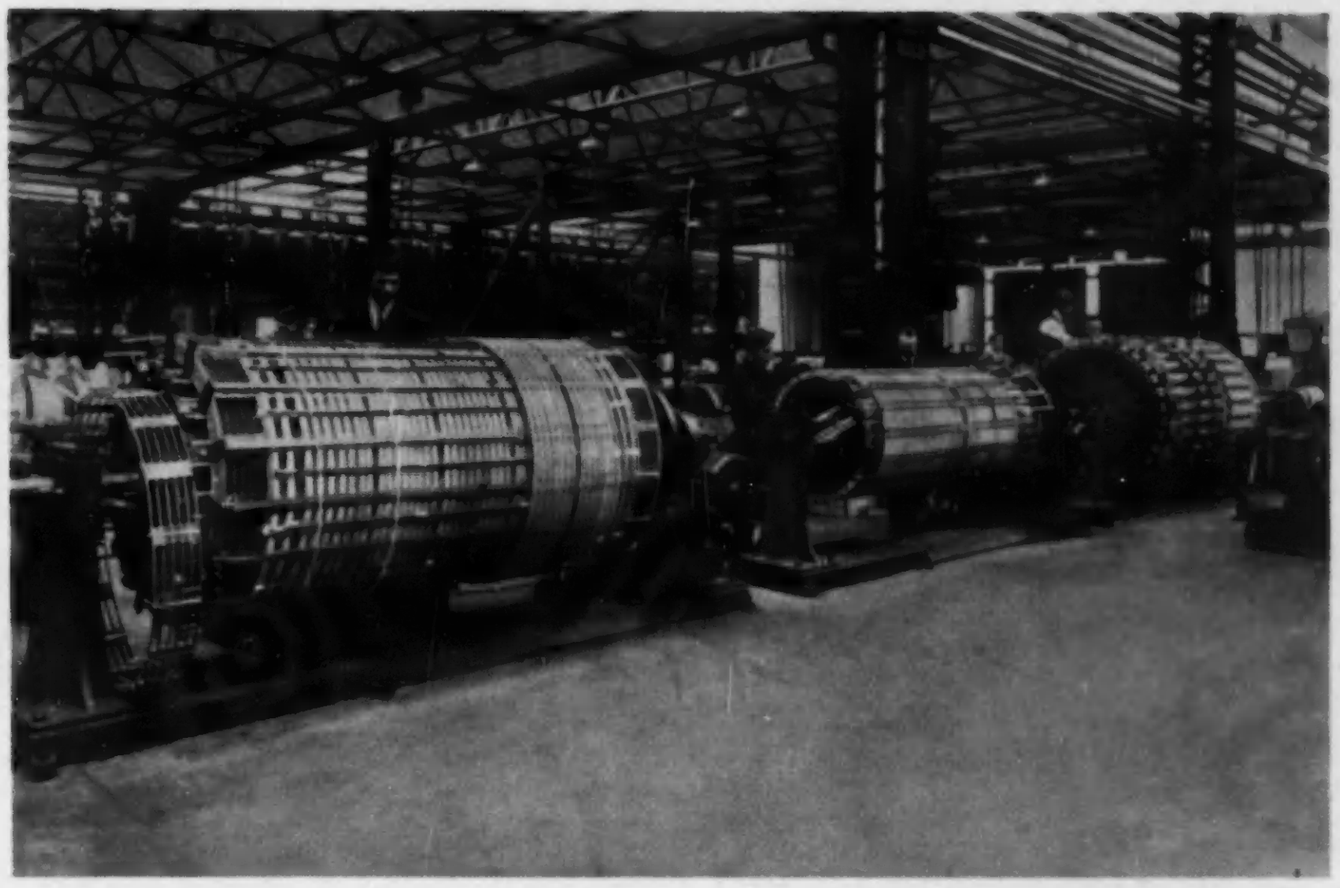


Fig. 18.—H.T. and l.t. coils being wound for one of the 30,000 kVA transformers for the British "Grid."

TURBO-COMPRESSORS.

Turbo-compressors of a single casing inter-cooler type have been developed. One of these is capable of compressing air from atmospheric pressure to about 90 lbs. per sq. in., and has eleven stages of the usual type.

PULVERISED FUEL.

Extensive experiments in the uses of pulverised fuel have been carried out, more particularly for Lancashire boilers and metallurgical furnaces. As the outcome a system employing a new type of solid injection burner has been introduced. Coal is conveyed by mechanical means thus obviating excessive wear caused to pipes and other apparatus when high velocity air is employed. Air for combustion is easily controlled and mixed with the coal in the burner itself. Coal is fed out of a small hopper into the solid injection burner by an adjustable screw feeder, which can be calibrated so that the feed to each boiler can be determined within reasonable limits. This offers an advantage over air circulating systems, with which only the amount of coal fed to the main can be measured.

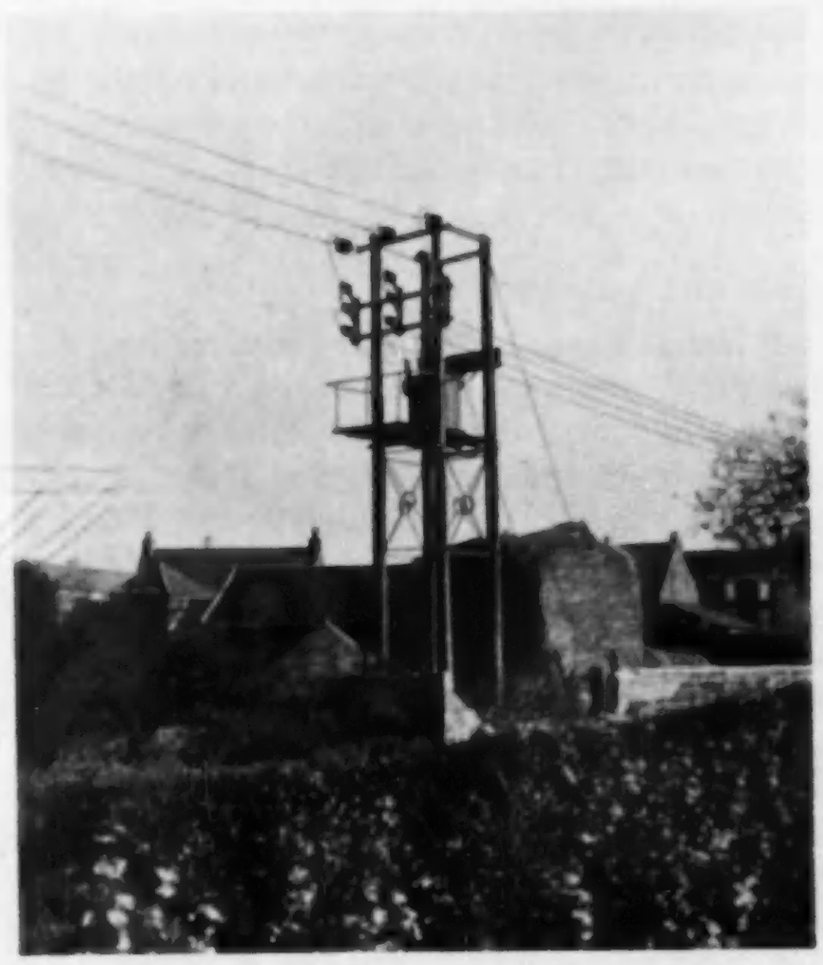


Fig. 17.—A typical outdoor sub-station for a Yorkshire rural electrification scheme.

OIL ENGINES.

There is a good deal of scope for oil engines for driving electrical generators, more particularly overseas. One of the latest types built is a 1,700 b.h.p. 6-cylinder engine driving a 6,600 volt alternator which has been put into commission for the Jaffa Electric Supply Company of Palestine. As the alternator is of the fly-wheel type, the rotating weight and its disposition had to be carefully calculated to avoid running anywhere near a critical speed. It is vitally important in oil engines of this power and speed (namely, 300 r.p.m.), that the major harmonics should occur at least 35 per cent. to 40 per cent. away from the running speed. If an engine runs within 10 per cent. to 15 per cent. of the critical speed it may possess a lesser amplitude of vibration and this may cause disturbance, vibration and chattering of the working parts.

Another unit for the Basingstoke Corporation consists of a 5-cylinder engine driving an alternator. The power of the engine is 1,350 b.h.p. and the capacity of the alternator 950 kW. The control of the engine is carried out entirely from the floor level, the attendant is thus able to devote his

whole attention to the engine without moving from one position. The fuel consumption of this unit works out at .57 lbs. per kW.

TRANSFORMERS.

One of the noteworthy events of the past year has been the increase in the number and size of transformers manufactured. This is largely due to the completion of the new Transformer Works at Witton which provides greatly increased facilities for transformer building. Work is now in progress on the 30,000 kVA 3-phase transformers for the Mid-East Grid Scheme. These units are designed to deal with a load up to 15,000 kVA under natural radiating conditions for which purpose special radiators are fitted. For the 30,000 kVA load a forced air blast is directed on to the radiators by suitable fans and motors from an air duct built round the base of the transformer. The motors are automatically started at half load by thermostat control. Two units are designed for a ratio of 132/11 kV and four for a ratio of 132/66 kV at 50 cycles per second, while on-load ratio control gear is fitted for tap changing under load, giving a variation of the effective transformation ratio from 10 per cent below normal to 10 per cent above normal in steps of 1.43 per cent of the normal ratio. The gear is arranged for remote electrical operation with provision for local and hand operation.

For the Waitaki Power Board, New Zealand, two 16,500 kVA three-phase transformer banks and a spare 5,500 kVA single-phase unit (fig. 16) have been constructed, each with a ratio of 66/110 kV, star-auto connected, a third winding being fitted to supply a 10,000 kVA synchronous condenser at 11 kV.

Another item of interest was a testing transformer built for a secondary voltage of 350 kV at 40 cycles per second. The incoming 440 volt supply is taken through an induction regulator, one end of the high voltage winding being permanently earthed to the tank.

The growing demand for the load ratio control type of transformer has been met by the development of two types of on-load ratio control gear, one for large three-phase transformers of 10,000 to 60,000 kVA and the other for smaller units of 500 to 10,000 kVA. The larger type, as previously indicated, is being fitted to each of the six 30,000 kVA transformers being built for the Grid, while several of the lighter duty type are being manufactured, of which one is complete with full automatic control on a 1,000 kVA transformer of 22/11/6.6 kV ratio at 50 cycles per second. On-load ratio control gear has also been designed for low voltage heavy current duty, the switches being fitted on the lower voltage side of the transformers.

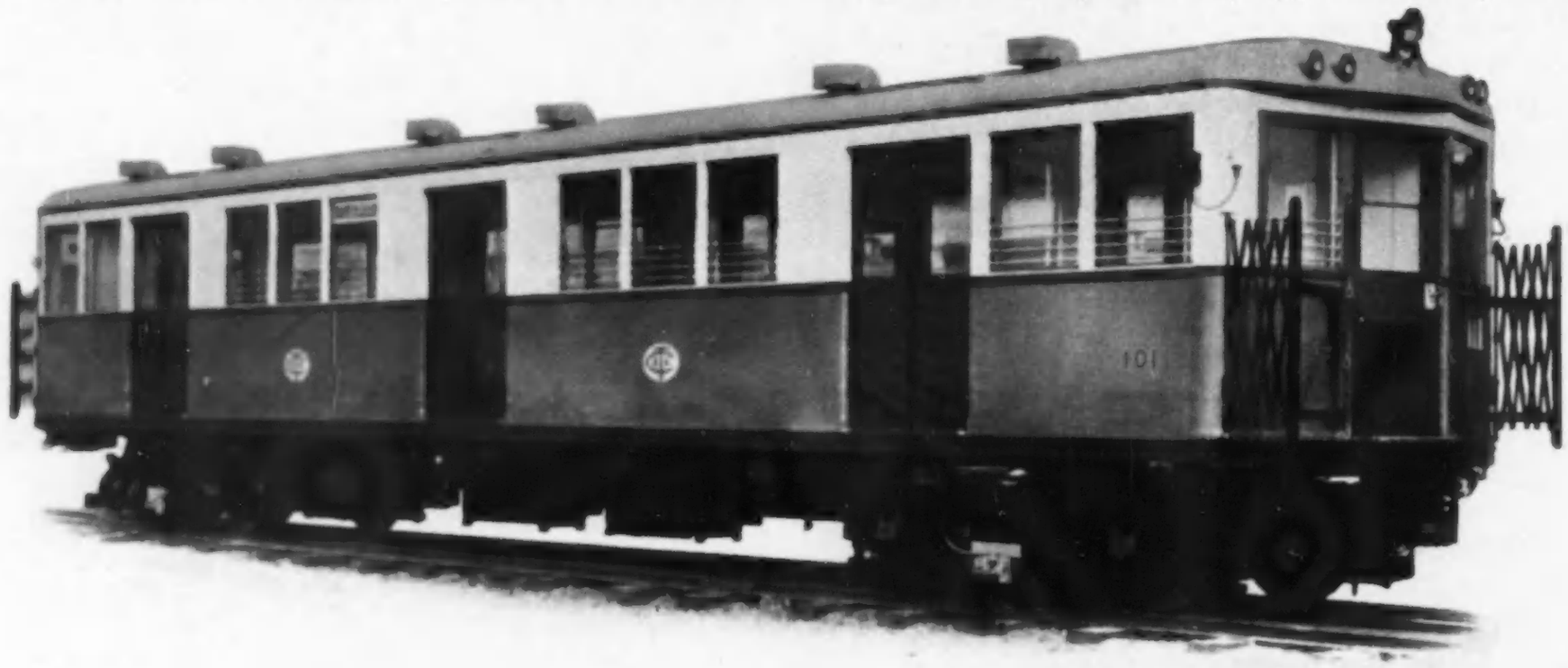


Fig. 19.—One of the 56 motor coaches for the Buenos Aires Terminal Central Railway.

ELECTRIC TRACTION.

A varied range of traction activities has been in progress through the course of the year, for though the greater part of the work undertaken has involved motors and control gear forming motor coach and tramcar equipment, two Diesel-electric locomotives were shipped for the Indian State Railways and development work relating to trolley buses has been carried out in conjunction with an important firm of vehicle builders.

The most important scheme however, has been in connection with the Manchester-Altrincham line electrification, which—as is now generally known—is the first suburban railway electrification scheme in the country to be operated at 1,500 volts on the D.C. system. Trial runs on this new system have been made with entirely satisfactory results. A

point of great interest in the equipment is that the whole of the apparatus comprising the main power and high tension auxiliary circuits is protected by means of a fuse on the roof and also a circuit breaker which was specially designed for the purpose. The electric heating of the coaches from a 1,500 volt supply raised various problems. In order to comply with the requirements a scheme was patented by the G.E.C. embodying, in particular, characteristics rendering it entirely mistake-proof.

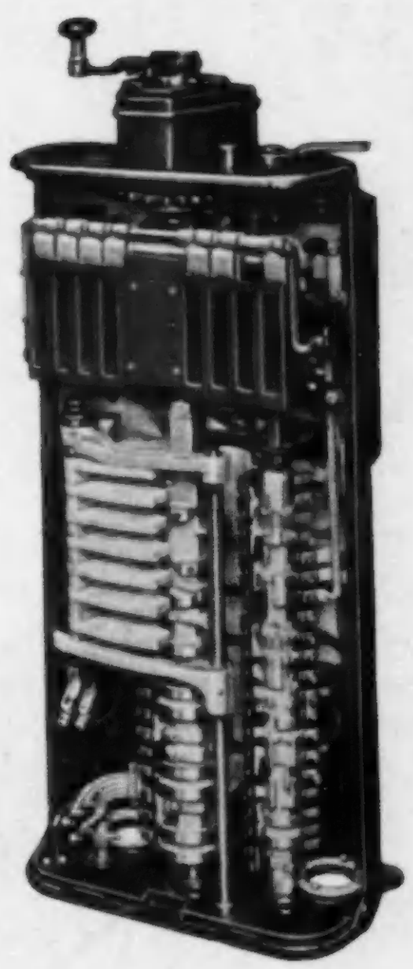


Fig. 20.—Cam type controller for the London United Tramways.

The equipment of 56 motor coaches (fig. 19) for the Buenos Aires Terminal Central Railway has been completed, and the coaches are now in regular service. A full description of these equipments will be published in an early issue of the *G.E.C. Journal*.

Work is also in progress in connection with the electrification of the Chinwangtao lines of the Chinese Engineering & Mining Co. (Kailan Mining Administration). Substation gear and overhead line equipment for the 1,000 volt D.C. supply has already been despatched, and the two 500 h.p. shunting locomotives are almost completed.

Reference should be made to a new type of cam controller for the London United Tramways (fig. 20). In this controller all contacts which are subjected to heavy arcing are arranged in the form of cam operated contacts, while those not subjected to heavy arcing are arranged on the usual system of drum contacts with blowouts. Contacts which do not require to break an arc, are of the usual drum type without blowouts. The controllers are also fitted with line switch equipment to meet specified requirements, whereby the arcing under all normal circumstances, takes place on external contactors and not on the controller. This is arranged by a mechanism in the top of the controller which de-energises the line switch as soon as the main handle of the controller is moved back a matter of a degree or so.

POWER APPLICATIONS OF SMALL CAPACITY.

Much attention has been given to the development of fractional horse-power motors for special purposes. One of the types of these motors is for gramophone drive. Simplicity has been the aim of the design, and the success obtained in achieving this object is illustrated by the ease of control provided, the elimination of gearing resulting in extremely quiet running, and the readiness with which the unit may be fitted in the gramophone cabinet. The motor is universal, running equally well on alternating current from 25 to 60 cycles, and on direct current.

The requirements of the artificial silk industry have led to the production of a motor for driving spinning bowls at 10,000 r.p.m. The bowls have an internal diameter of 6 inches, and an external diameter of 7 inches. This means that the bowls rotate with a peripheral speed of 3½ miles per minute. The balancing of the system must therefore be extremely accurate, for the least out-of-balance would cause tremendous vibrations. To guard against such effects the motor is arranged on the spinning top principle, so that the bowl is able to revolve round its own centre of mass independently

Fig. 21.—A new lamp development, the Gothic candle lamp used in an appropriate fitting.

of the constraining centre of the motor shaft. The bowl is also free to precess at a different periodicity from that corresponding to the speed of the motor. These results are accomplished by a special arrangement of flexible shaft and by flexible mounting of the motor within the constraining stand.

Apart from such special machines as those just described a new range of small motors has been developed for purposes which require considerable effort at starting. The starting of these motors is on the repulsion principle, but as soon as full speed

is attained they are switched over to run automatically as induction motors with shunt characteristics. Quietness of running is ensured by the design of the air circuit which is stream lined; moreover the brushes are mounted in a special way so that brush noise is eliminated.

A new fan which should prove a boon in hot countries has been christened the "Mosquito." Its principal object is to prevent mosquitoes and other

Fig. 22.—3 kW cinema studio projectors in action.

insects from attacking the ankles and legs. It stands on the floor and causes a slowly rotating "beam" of air to circulate about the legs of those sitting anywhere near. The design is interesting, in that the fan and motor have their axes vertical and are surrounded by a circular case which is free to rotate. This case, which has a vertical slot, is so shaped that it rotates slowly when the fan is running, the rate of rotation being fixed by means of a simple governor. The range of service of this fan may be extended by fitting it with a heating element so that a stream of hot air may be obtained if desired.

Another new appliance takes the form of a hand drier capable of delivering hot air in any direction round a horizontal axis, so that its use is not confined to hand drying, but may be extended to drying the face or body generally.

LAMPS AND LIGHTING.

The main feature of lamp progress during 1930 relates to the Simplified Line of Pearl Osram lamps introduced two years ago. It was then considered that this line of lamps would meet all requirements for normal lighting work to a greater extent than any lamps previously in use.

The accuracy of this opinion has now been proved by the fact that more than double the quantity of Simplified Line lamps were sold in 1930 than in any previous year, the proportion of lamps up to and including the 100 watt size amounting to nearly 70 per cent. of the total. This progress has led to price reduction. It has also entirely justified the policy of building a new Osram Lamp factory at Wembley, to be used for the manufacture of the type of the Simplified Line sizes. The equipment installed and the methods employed in this factory are representative of the most recent advances in engineering and science, as may be appreciated by reference to the article appearing on page 175 of this issue, "The Mass Production of Incandescent Electric Lamps," by G. Chelioti.

Continuous investigation of the lamps comprising the Simplified Line has enabled their light output to be increased by a further 2 per cent. without any reduction in life. It has also enabled the uniformity of lamps to be improved, the previous manufacturing tolerance of 28 per cent. being reduced to 20 per cent. Moreover there is definite indication of still further progress in the production of a uniform lamp.

Fig. 23.—A 10 kW cinema studio projector, with 10 kW Osram lamp and starting gear.

Collaboration between the makers and users of Striplite lamps has made possible important changes in the design, tending towards a reduction of superfluous types and improvement in light output and uniformity of life; the prices have also been reduced. This standardization has enabled greatly increased use to be made of Striplite lamps, which can now be used in modernistic lighting installations, such as that at the rebuilt Strand Palace Hotel, London, where four or five thousand of the lamps are in use.

Similar collaboration has led to a reduction in the number of types of sign lamp required without in any way reducing the freedom of design of signs. One result has been the introduction of a 15 watt Osram sign lamp suitable for use on both low and high voltages. This new lamp reduces the cost of running signs by 25 per cent.

Among minor introductions is a type of candle lamp, named the "Gothic" (fig. 21), which marks a new development in the design of artistic electric lighting fittings. Another development to be recorded affects lamps of the well known colour sprayed type, in which the unchangeable mineral coating with its pigment is applied to the inside of the bulb instead of the outside. A material improvement in the appearance of the lamp has resulted, and it is now proof against deterioration due to the effects of weather and dirt. These lamps, though not yet finally perfected, have already been shown to possess advantages which render them superior to the externally sprayed lamp.

An important improvement has been made in the design of large Osram gasfilled lamps of 500 watt rating and upwards, which are now available for burning at practically any angle without appreciable loss of life. This makes them suitable for use in floodlight and other fittings which necessitate the burning of lamps at angles other than the normal position.

The introduction of an alternative type of neon indicator lamp follows the demand created for this very low consumption indicator introduced in 1929. The new type, while consuming only one or two watts, has an improved electrode giving a more powerful indicating light, thus making the lamp more suitable for use with switchboards of the electric cooker and similar types, which are often situated in rather brightly lit surroundings.

Fig. 24 (*Above*).—**A view by day of the New Lock, Tilbury Docks.**

Fig. 25 (*Left*).—**A similar view by night showing the illumination obtained by the use of G.E.C. Dock Navigation lighting Lanterns and Osram lamps.**

Cinema studio lighting has made rapid strides during 1930 (fig. 22). New lamps and new types of apparatus to meet the requirements of cinema studios have been developed with considerable success, in consequence of which large quantities have been sold not only to British studios but also for use in Continental studios. These lamps are very large, ranging up to sizes as high as 10,000 watts (fig. 23). Simultaneously with the improvement in the design of lamps for use in cinema studios, advances have been made in the range of projector lamps for use in optical lanterns for cinema projection and in various other high grade optical appliances.

Aerodrome lighting has become a field of active study. The requirements are naturally out of the ordinary and floodlights of a size and design capable of illuminating the whole of an aerodrome from one unit are being made. The floodlight itself can be mounted in a truck enabling it to be moved to any position required. Boundary lights, indicating the boundary of the aerodrome have also been designed, making use of the principles developed in connection with the G.E.C. constant current series street lighting system. Beacons of sufficient intensity to be visible at forty miles and many other types of lamps for aerodrome service are now available.

Fig. 26.—The lighting of Hounslow High Street, London.

In addition to the lighting of cinema studios and aerodromes many other examples could be given of specialised applications of lighting; progress in scientific illumination is best measured by this fact. Whether the scheme is for interior or exterior, for industry or entertainment, for a narrow street or an extensive dockyard—whatever the class of space to be lighted—the choice of lamps, fittings and reflectors has to be considered in relation to factors peculiar to the surroundings. Thus the science of illumination has developed from the stage when certain general standards were applied to the solution of almost any problem, until to-day each class of installation is dealt with on special lines. And further, an individual scheme may involve several different forms of lighting as shown by the dock lighting system just installed for the Port of London authority which includes the illumination not only of quay sides, but of locks, gravity docks, floating landing stages, cargo loading and boat launching positions and the like (figs. 24 and 25).

As evidence of the wide variety of method which has to be applied it will be of interest to refer to other schemes recently completed. These include the illumination of Hounslow High Street (fig. 26), the interior of Southwell Minster (fig. 27), the exterior of Olympia, the swimming bath of an Indian Maharajah, the Great Hall of the Guildhall, the Head Office of one of the largest banks in the country, and many churches, cinemas, schools, factories, main streets, smaller thoroughfares and other open spaces.

CABLES.

The most outstanding matter of interest in the development of cables has undoubtedly been the rapid progress of oil-filled cable. This subject is however so well covered by the series of articles by R. E. Horley in the *G.E.C. Journal**, that only a brief résumé need be given. By the end of 1928, 66 kV oil-filled cable forming part of a contract for both 66 kV and 132 kV cable of this type had been completed, and as further plant was necessary for the manufacture of the 132 kV cable, the Pirelli-General factories were extended by the erection of several new shops, which were equipped also for the production of 220 kV oil-filled cables.

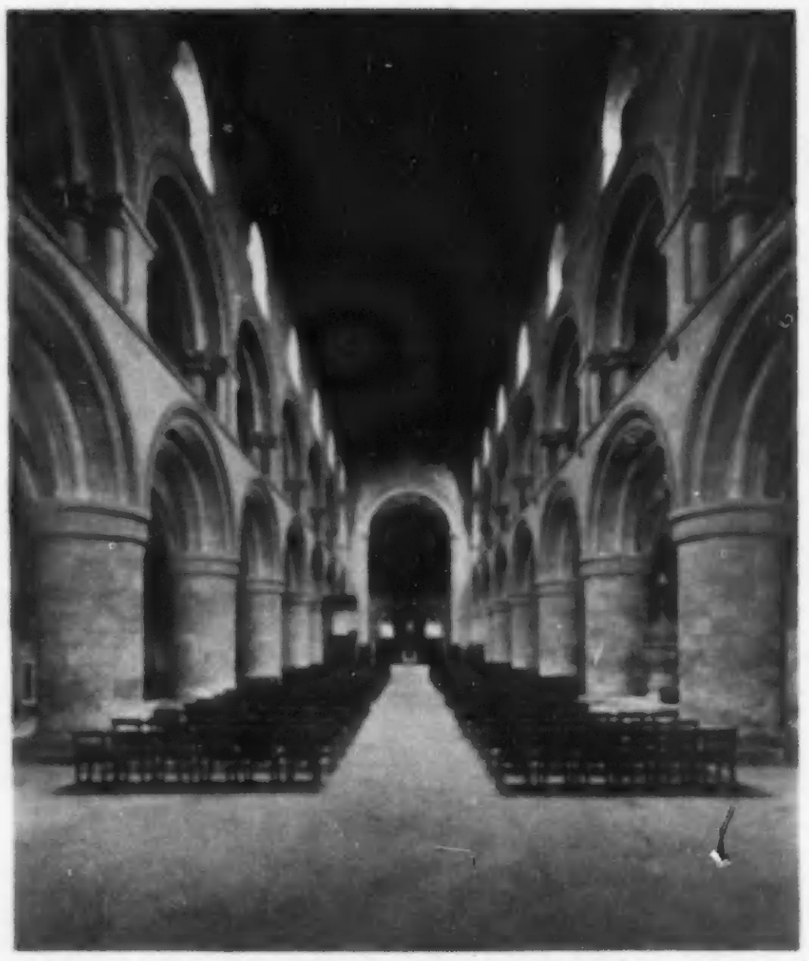


Fig. 27.—Southwell Minster from west end—a view taken at night, showing the even illumination of the nave.

Particular attention has also been paid to developing the accessories needed for oil-filled cable systems. As a result of experimental work improved designs have been made which have given better mechanical

* Oil-Filled Cables, Vol. 1, Nos. 2, 3 and page 175 of this issue.

and electrical working, together with a reduction in costs. The installation of these accessories has formed an important part of this work, and satisfactory results have attended endeavours to produce accessories for the lower voltages, which can be buried in the ground with the cable, thus obviating the necessity of providing special housings for them. The need for providing smaller joints has also been efficiently met.

The realisation of the advantages of a three-core oil-filled cable for lower voltages gave use to continuous research being undertaken. This proved so effective that towards the end of the year this type of cable was made possible for working pressures of 33 kV and 66 kV. Such a development means that all the advantages of three core cable are combined with those of the oil-filled cable.

In view of the fact that the carrying capacity of this cable is considerably higher, relatively, than that of an ordinary three-phase cable for 33 kV working, the oil-filled cable for the same carrying capacity is much smaller in diameter; this allows greater ease in handling. Moreover, as three oil ducts are incorporated in the interstices between the cores, it is possible to maintain the necessary oil pressure needed for maintaining the impregnation with a reduction in the number of accessories required, owing to the fact that these three ducts are connected to specially designed common oil pressure accessories.

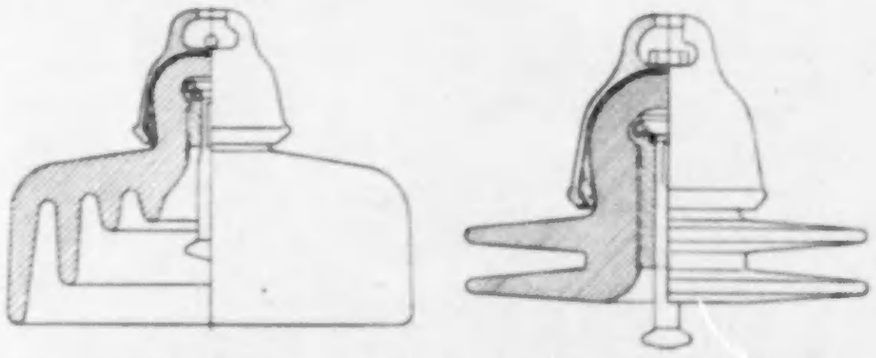


Fig. 28.—Two forms of anti-dirt insulators developed for use in industrial areas.

The higher carrying capacity is of great importance when considering cables for 66 kV working as a three-core cable of the ordinary type, for this pressure is necessarily of such large diameter that it is only possible to install short lengths, due to difficulty in handling and the considerable increase in the number of joints necessary for an installation.

Apart from oil-filled cable much attention has been given to improving the triple lead sheath type for 33 kV working. In this connection an improved design of joint has now been produced, of which one of the features lies in the fact that two Pirelli patent paper tubes are used in the manufacture so as to give a higher breakdown value, whilst a reservoir dome type lead sleeve is adopted which compensates for any migration of compound due to temperature changes inside the joint.

Activities in regard to the development of telephone cables have focussed on the design and

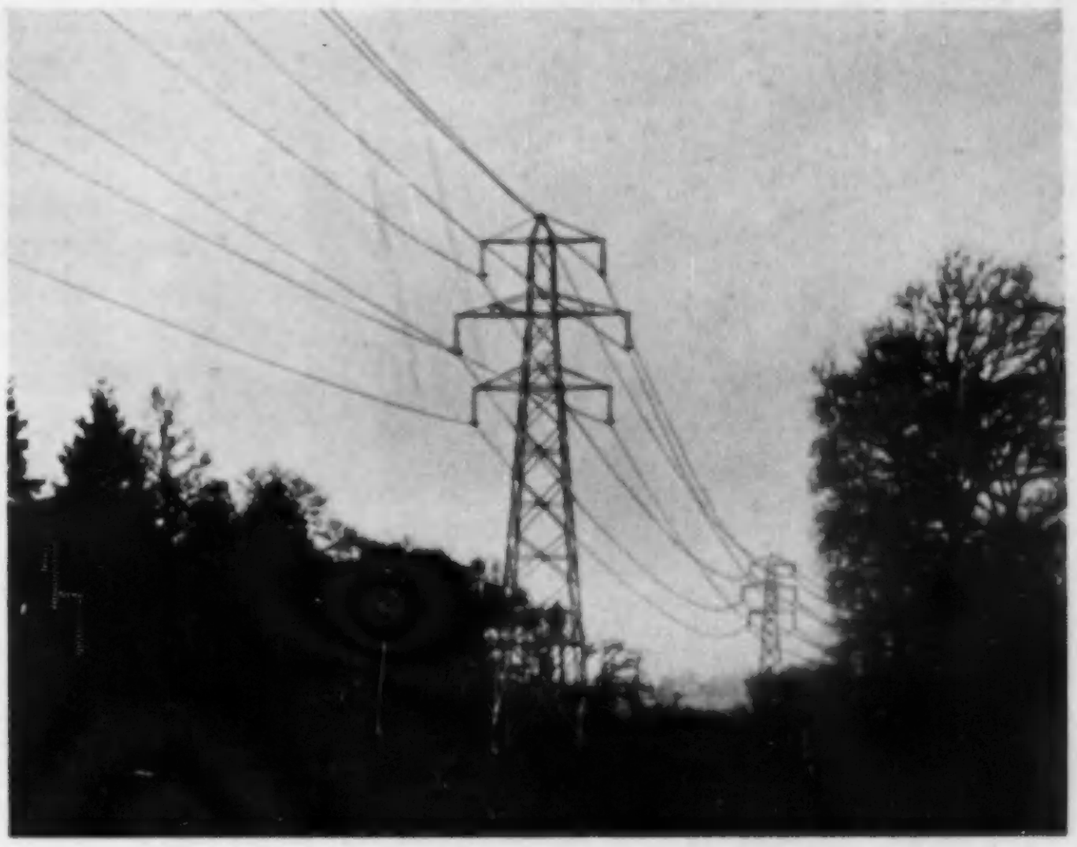


Fig. 29.—132 kV overhead transmission line on the Bedford-Luton section of the British "Grid."

methods of manufacture of the new type quad trunk cable to meet the demands of the British Post Office. The equipment of the Eastleigh factory has been completed during the year and cable of this type, possessing extremely uniform electrical characteristics, is now being manufactured under commercial conditions. Already three contracts from the British Post Office have been received for loading coils and terminations, and in each case the cable includes circuits specially designed for the transmission of broadcasting music. The loading coils have also been designed from the point of view of broadcasting.

A light gauge quad cable has been supplied to the Post Office who are carrying out experiments with a view to its replacing the old type subscribers' twin cable by star quad cable. The great advantage of star quad cable is that approximately 50 per cent. more pairs can be accommodated in the same diameter lead sheath; this effects considerable economy in duct space.

OVERHEAD TRANSMISSION.

During the year development work and testing have been proceeding on the earth conductor with an embedded pilot wire and considerable technical improvement has been made. Difficulties were encountered in the early types manufactured owing to elongation after erection, resulting in increased

sag. Attention was therefore devoted to a modification of the mechanical characteristics of the conductor. The pilot consists of a lead sheathed cable embedded within, and protected by, the earth conductor itself, and very satisfactory types of

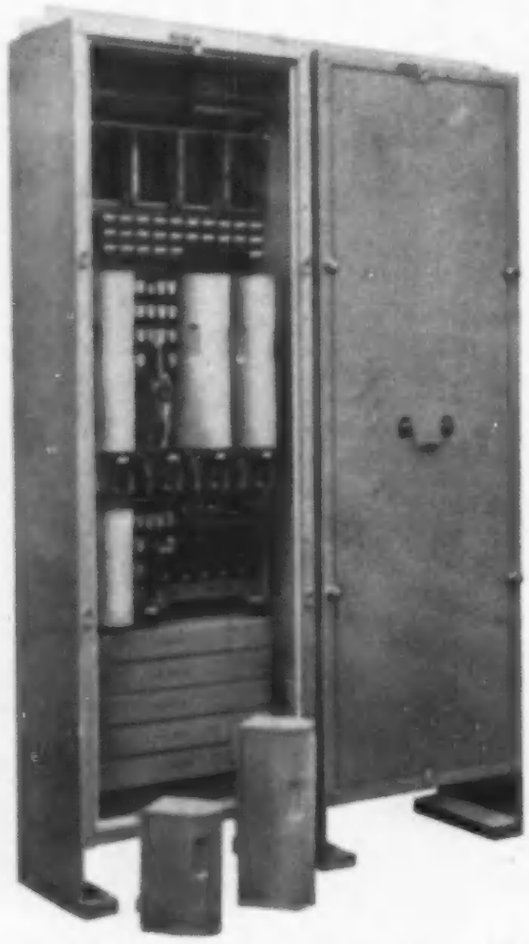


Fig. 30.—Two 25-line rural automatic units lined up to form a complete 50-line automatic exchange.

clamps and joints have been developed for use with this conductor.

A special type of composite line conductor suitable for rural transmission lines has been developed. This conductor provides a higher tensile strength than ordinary hard drawn copper without greatly affecting the conductivity and without incurring any increased liability to corrosion. It is therefore suitable for lines of moderate carrying capacity, where it is desired to employ long spans.

Minor improvements have been effected in the standard type of construction for 11 kV lines, particularly with reference to earth bars for use at road crossings which are now secured direct to the patent pole top fitting and therefore require no separate bonding. A highly satisfactory and neat design of single terminal pole is now available and is particularly suitable, owing to its low cost, for terminal positions where an overhead line is connected to underground cables. An improved type of outside connector has been standardized for these line terminations, which provides secure mechanical fixing without the use of small bolts or screws. It is adaptable to varying angles of incoming tails, and may be quickly detached for testing or fault locating purposes.

Troubles arising through conductor vibration have been explored and designs have been produced for overhead line fittings which very appreciably minimise the possibility of these troubles.

Another problem tackled concerns anti-dirt insulators (fig. 28). A type of anti-dirt insulator has now been designed which will enable lines passing through industrial areas with contaminated atmospheres to be kept in service without cleaning for a much longer period than with the normal type of insulator.

It should be recorded that work on certain sections of the grid lines is in progress. Of new contracts placed, the scheme involving the crossing of the River Witham is of interest. It will involve two extra high towers with anchor towers for carrying three 33 kV three-phase circuits over the River Witham at Boston, and will afford 150 feet clearance above high water level.

TELEPHONES AND TELEPHONE EQUIPMENT.

The telephone density in this country expressed as the ratio of telephone subscribers to population does not compare favourably with that in certain other countries. But the position is improving. One factor in the improvement lies in the development of apparatus of a character suitable for extending telephone service in rural districts. This takes the form of a new type of automatic exchange

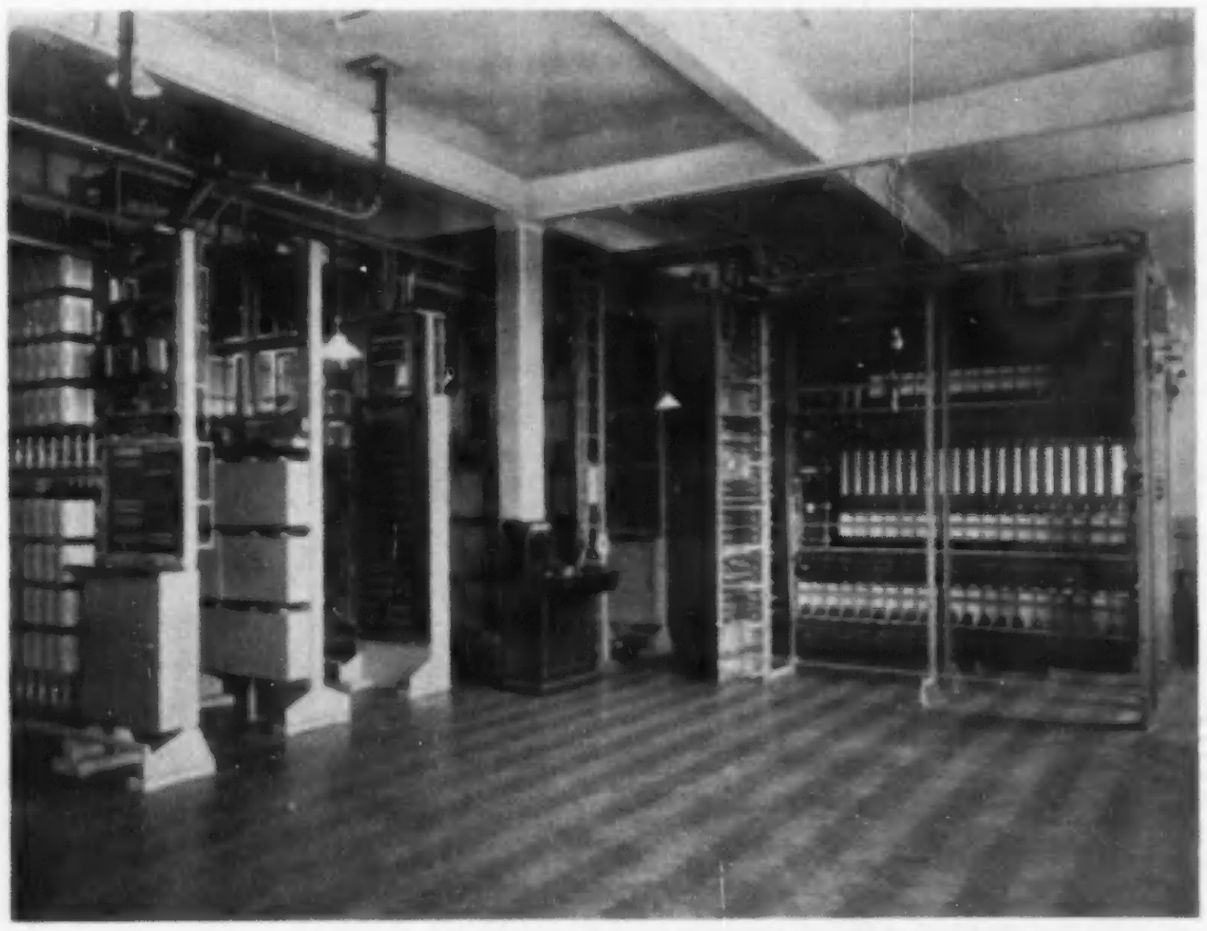


Fig. 31.—Key sender, director and code selector equipment at Fairfield Automatic Exchange, Croydon.

(fig. 30) applicable to small rural communities and enables a reliable twenty-four hours service to be offered to rural subscribers. Since this exchange was adopted for service in 1928 over 700 fully equipped units have been supplied from or are under construction in the Telephone Works at Coventry.

The erection of large provincial public exchanges is continually in progress, Manchester, Birmingham, Glasgow and Preston affording examples of towns in which such work has either been completed or is still being carried out. The extension and improvement of trunk telephone service has also led to an increased use of thermonic repeater equipment. The Canterbury repeater station is particularly noteworthy as a large portion of the telephone traffic between this country and the continent passes through it.

Another important step forward has been in connection with the new automatic exchanges of the Director type opened recently in the metropolitan area, for that which now serves Croydon marked the introduction of automatic excess fee metering (figs. 31 and 32). By means of this feature a subscriber not only selects and calls another by the simple action of dialling, but at the same time, in operating a meter, registers a fee which varies in accordance with the distance of the call. Hitherto local calls only, for which a fixed charge is made, have been registered automatically while excess fee calls have necessarily been noted through a manual operator who recorded them on a ticket.

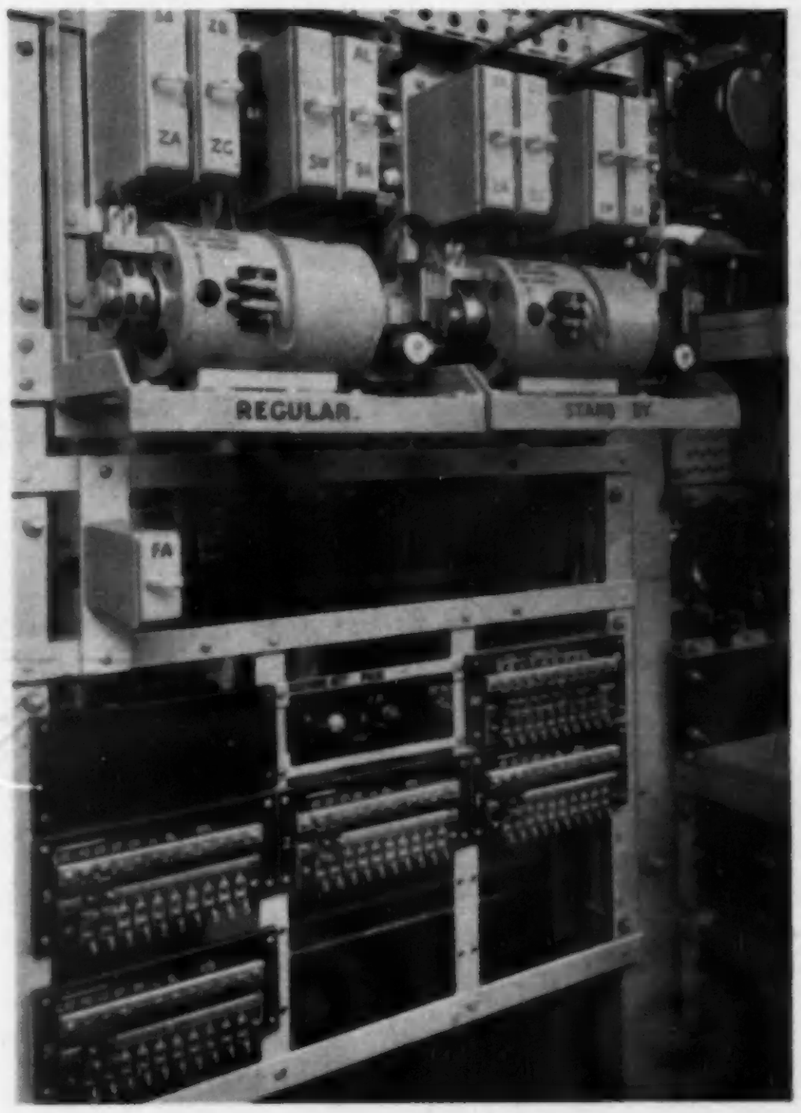


Fig. 32.—Meter pulse machines and associated equipment to provide automatic excess fee metering at Fairfield Exchange, Croydon.

Of more general application is a new form of subscribers' telephone which represents a great

Fig. 33.—7½ kW electric coil drying oven, size of chamber, 3ft. by 3ft. by 4ft. high.

advance over earlier types both in efficiency and appearance (fig. 35). It is of interest to note that the principal external parts are made entirely of bakelite mouldings produced in Witton Moulded Insulation Works. The best tribute to this new instrument is found in the fact that apart from a heavy demand in this country, it has been adopted for public services throughout various colonies.

Rapid strides have been made recently in the development of carrier current telephone systems which enable lines employed for various purposes to be used simultaneously for telephony, telegraphy or simple signalling. The wide application of such schemes to e.h.t. transmission networks is likely to be seen in the near future. Evidence of this is afforded by the contract recently received for the first installation in Great Britain of a "Wired Wireless" system giving full duplex telephone service super-imposed on 132 kV lines operated by the Grampian Electricity Supply Co. between Rannock and Abernethy.

The manufacture and supply of telephone equipment for overseas purposes is now of large volume. In April last, one of the largest contracts ever undertaken for the supply and installation of a modern automatic telephone system abroad was completed when the new Singapore telephone service was opened. This equipment consists of three exchanges, having a total capacity of 10,000

lines, and is of outstanding interest not only on account of its size but in view of the severe climatic conditions under which it is required to operate.

INDUSTRIAL HEATING.

Few branches of electrical engineering have grown more rapidly than that of industrial heating; in particular, furnaces for the heat treatment of metals are very much more widely in service than heretofore. The size of such furnace installations is increasing, a multi-car hearth type furnace just manufactured having a total effective hearth area 24 feet long by 7 feet by 5 feet wide. Other furnaces constructed which should be mentioned individually are, first, a small vertical cylindrical type for the precise and uniform heat treatment of gears, and secondly, an automatically controlled electric cyanide hardening pot which has now been in operation under ordinary shop conditions for several months.

Progress is being made in connection with the disposition of heating elements within electric furnaces of the resistance type. A very satisfactory method of suspending elements from the roof of the furnaces has been developed and furnaces of the car hearth type are now being fitted with hearth type heating elements without the use of trailing flexible cables, which are a source of inconvenience and danger.

In addition to furnaces suitable for the various heat-treatments of ordinary carbon and alloy steels, other types have been designed and built which are capable of more difficult and exacting heat-treatment to special steels and alloys. To obtain these results it has been necessary to ensure a definite and controlled temperature gradient between one part of the furnace and another. This is now accomplished with automatic temperature control gear and is quite dependable. Furnaces suitable for the case-hardening of special steels by nitrogen have also been introduced with entirely satisfactory results.

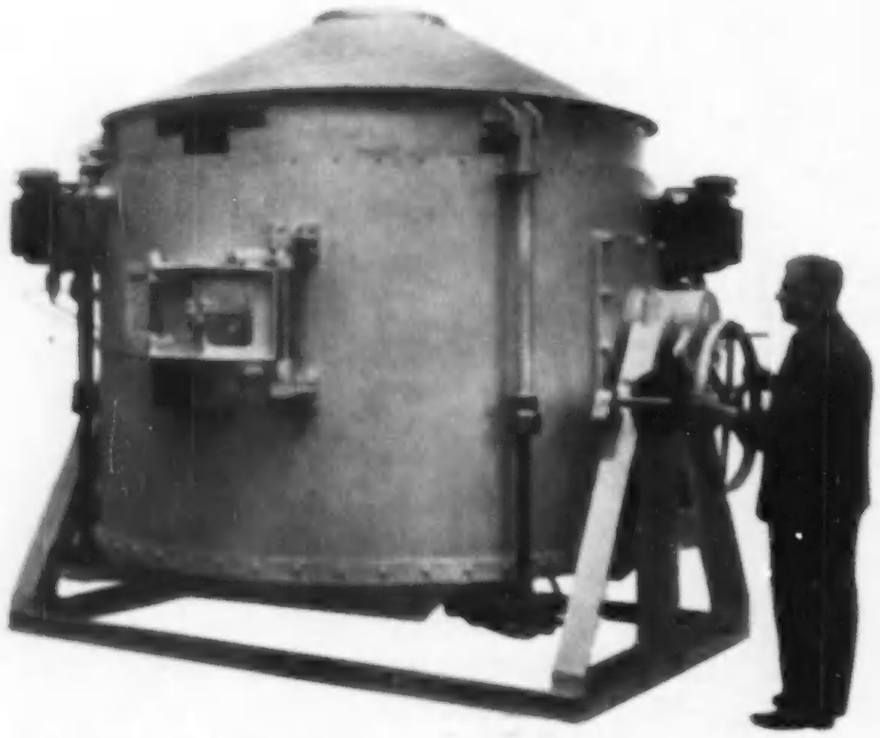


Fig. 34.—Brass melting furnace, capacity 2,000 lbs., electrical rating, 150 kW.

Steady progress is maintained in other branches of industrial heating, and electric water heating is now being performed on a large scale. A special heating application of a good deal of interest involves the heating of process air to a temperature of 750° F., control gear of novel design having been devised for the system.

Fig. 35.—The new subscribers' telephone is moulded in bakelite with all the connecting wires in position.

GENERAL ACTIVITIES.

It would not be possible to give even brief details of all the many improvements to plant and appliances which have taken place during 1930, but bare reference should be made to certain classes of apparatus whose progress is marked. For instance, special types of circuit breakers are available in extended ranges, such as the high speed breaker which is now made with a capacity of 3,000 amperes for 1,500 volt circuits. Improvements to the manufacture of ironclad switchgear have been numerous, particularly as regards quick make and break gear. Ranges of contactor equipment are being developed and applied in many new ways. Recent units for large mine hoists have capacities of 700 amps. for 3 kV and 6 kV circuits. A useful item of starter gear embodying contactors is a direct to line starter for small motors up to 5 h.p.

The increasing use of bakelite has been previously commented upon. It is now embodied wherever possible in electric light fittings, lampholders, bells and bell accessories, indicators and many other accessories. An application to a new telephone (fig. 35) referred to earlier involved very elaborate and complicated mould designs. Other moulded materials are utilised for many purposes. A new shop has been built for the production of composition accumulator containers.

Private automatic telephone exchanges are tending to supplant the manual type of intercommunication

'phone. Exchanges installed in important industrial undertakings, offices, hospitals and institutions have been very numerous during the past year.

Apart from progress in matters of an electrical character it remains to refer to certain developments of mechanical equipment, the manufacture of which is undertaken in Fraser & Chalmers Engineering Works.

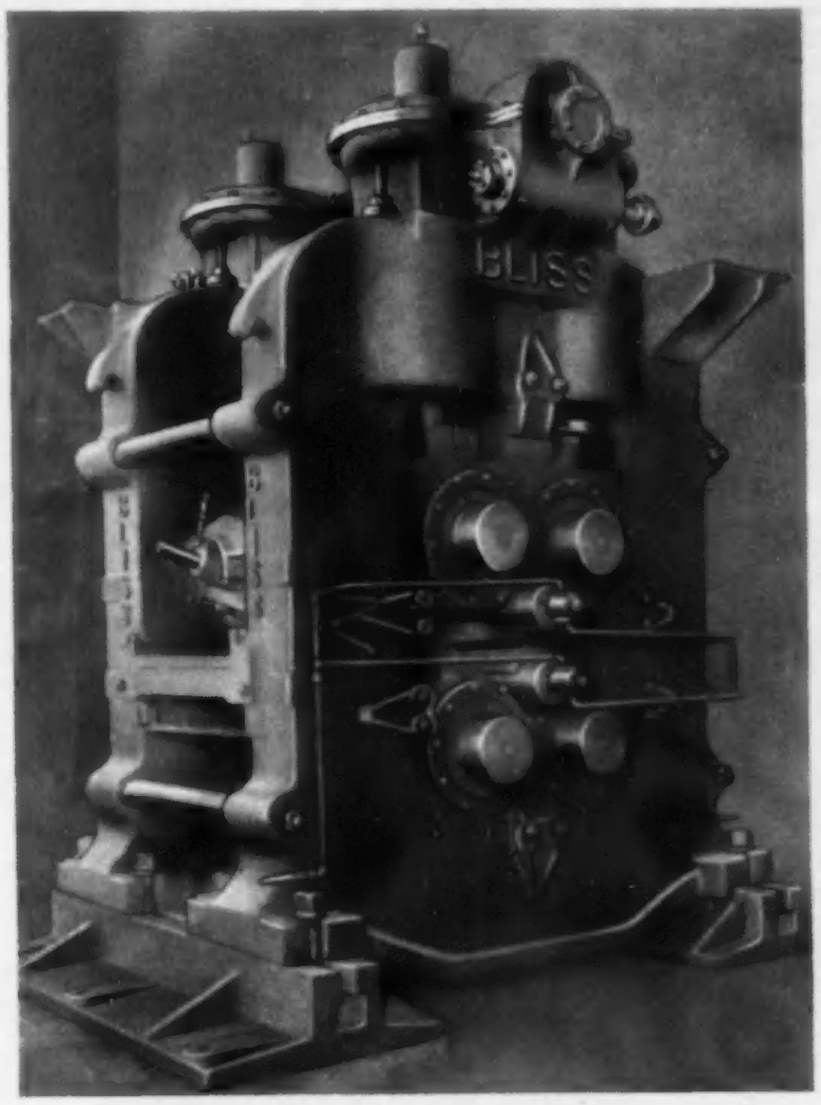


Fig. 36.—End view of Bliss Cluster Rolling Mill.

MATERIALS HANDLING PLANT.

Much attention has been given to methods to prevent the great economic loss due to coal breakage. Two designs of apparatus embodying anti-coal breakage features have been manufactured and applied with success. The first is a new wagon tippler intended primarily for locomotive coaling plant. It was developed to meet the increased demand for a means of unloading coal from railway wagons into storage bunkers arranged immediately above the tipping point. In such cases space limitations preclude the use of a belt conveyor, and formerly necessitated an underground hopper and bucket elevator or skip hoist. The risk of breakage of the coal, which is lifted in the wagon and lowered direct into the bunker is very greatly minimised due to the fact that it only has to fall through a very short distance. Furthermore there is no abrasion due to change points, or dumping, as is the case with elevators or conveyors.

The other device designed to overcome the coal breakage difficulty is shown in fig. 37. Its use is particularly applicable in the case of a boom conveyor for loading ships, although other applications are possible where material is lowered through a vertical distance and it is necessary that breakage due to fall should be eliminated. The device will easily deal with the capacity of any belt conveyor plant.

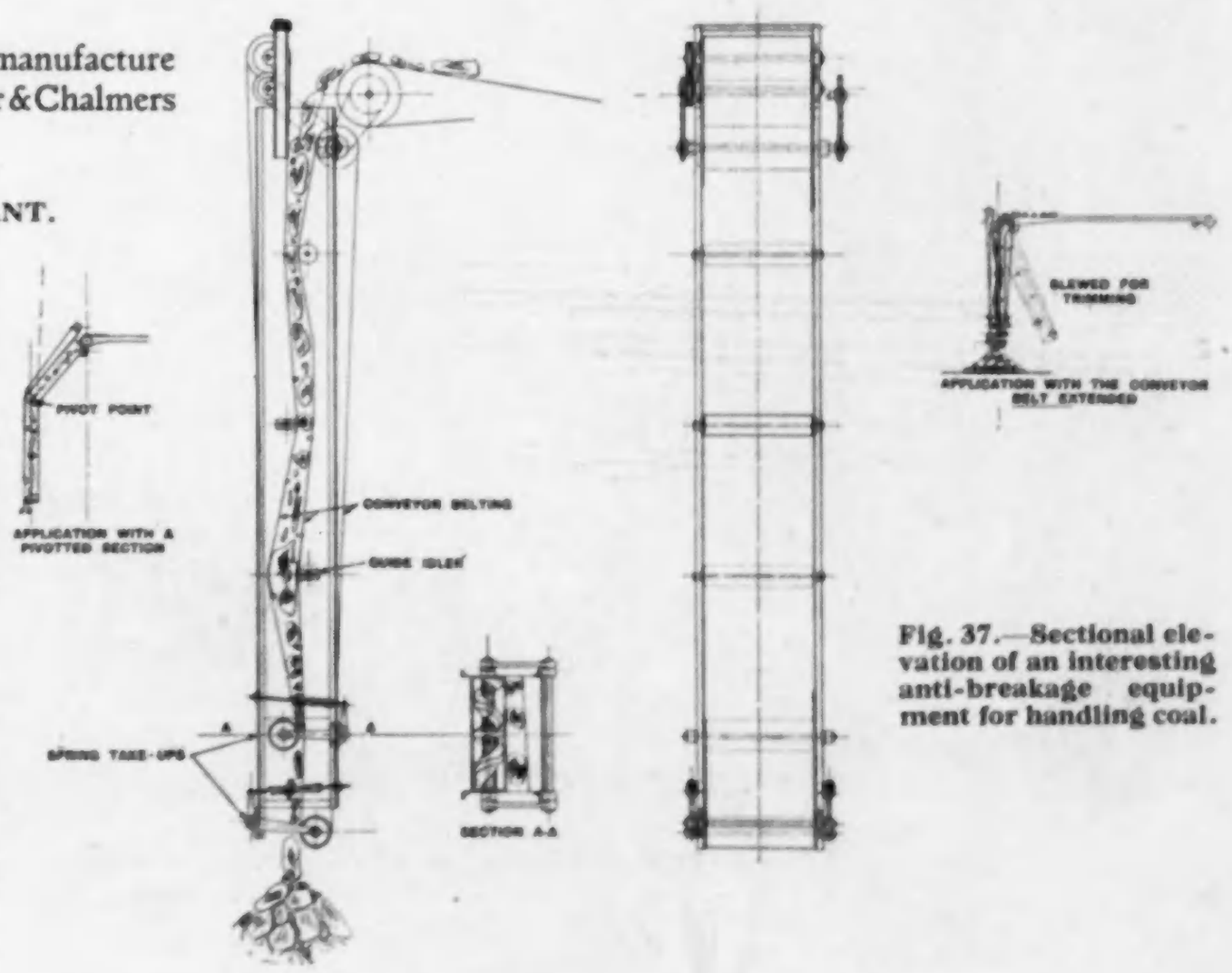


Fig. 37.—Sectional elevation of an interesting anti-breakage equipment for handling coal.

ROLLING MILLS.

An interesting development in rolling mill practice is marked by the Bliss Cluster Mill (fig. 36). Unlike the standard design of rolling mill, the Bliss Cluster and 4-high mills are highly perfected precision machines in which roller bearings are used on large diameter backing rolls and small working rolls. This arrangement makes it possible to obtain greatly increased rolling pressures and relatively greater reduction and lower power consumption. The mills are particularly suitable for cold rolling, and ensure a high degree of finish and a close rolled product of even gauge.

G3487

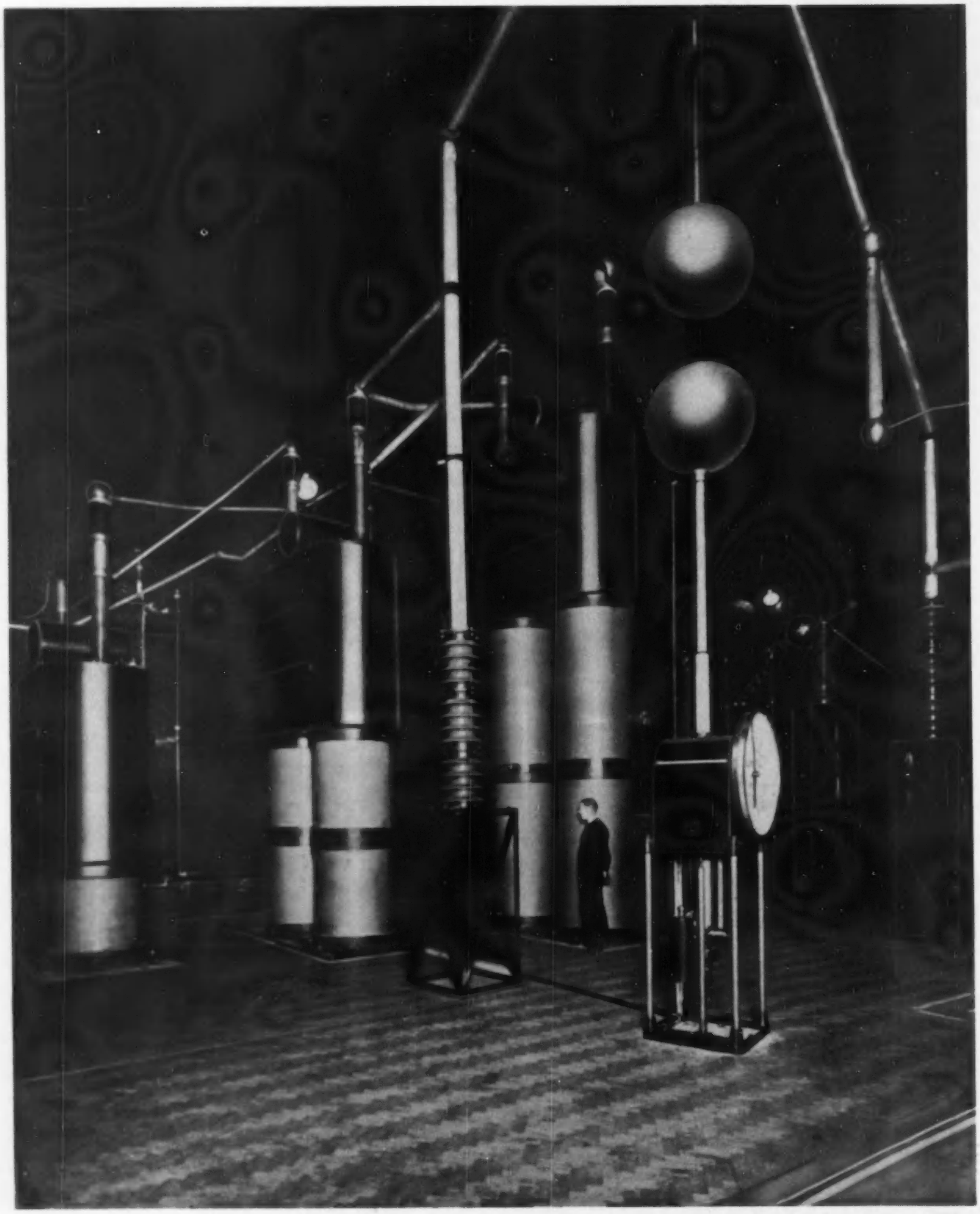


Fig. 1.—Cascade-connected million volt testing transformer at normal periodicity, with measuring sphere gap—High Tension Laboratory, Witton Works.

Insulation for 132 Kilovolt Electrical Apparatus.

With Special Reference to the G.E.C. High Tension Laboratory.

By CHARLES C. GARRARD, Ph.D., M.I.E.E., A.Am.I.E.E.
Manager of Switch and Transformer Dept.

IT is somewhat remarkable to find that if the construction of 132 kV electrical apparatus, such as is being manufactured for the Grid Transmission system in this country, be examined, the whole success of the gear depends upon the use of insulating materials which are, in essentials, those which were employed in the earliest days of electrical engineering. These materials are porcelain, paper and oil.

Ferranti in his epoch making installation at Deptford over 40 years ago insulated his 10,000 volt concentric cables with paper and oil; and these are the materials used for insulating the 132,000 volt cables now installed by the Pirelli-General Cable Works in the same neighbourhood. But if the materials are the same, the advance which has been made in the meantime in technique and constructional methods has been tremendous. Apart from one newly invented material —bakelite—progress has been made by a gradual improvement in details. These improvements however have been so great as to constitute, in fact, considerable inventions in themselves. Progress of this nature can only be made by continual testing and research; and as investigation into phenomena associated with 132 kV apparatus obviously involves tests at considerably greater voltages, the need is immediately created for a laboratory with highly specialised equipment. It is to meet this need that the G.E.C. has equipped a High Tension Laboratory at Witton Works, which enables a complete study to be made of the behaviour of insulating materials and apparatus when subjected to electrical pressures up to one million volts.

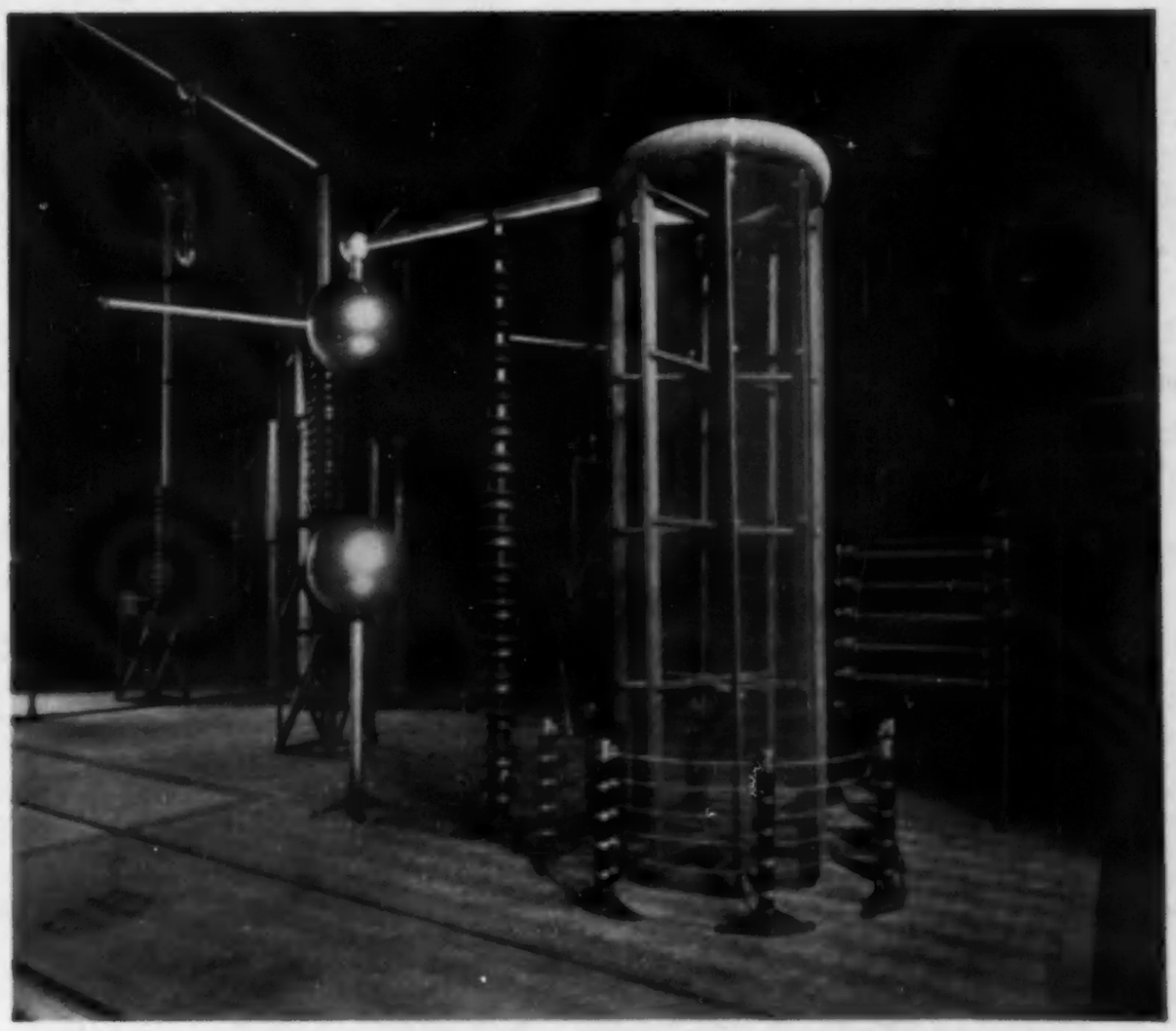


Fig. 2.—High frequency generator (Tesla coil).

To provide the power for testing there are three principal items of apparatus in this laboratory, a 50 cycle cascade transformer (fig. 1), high frequency generator (fig. 2), and surge generator partly seen in the centre background of fig. 3. Each of these is capable of giving one million volts. The further resources of the laboratory include a combined

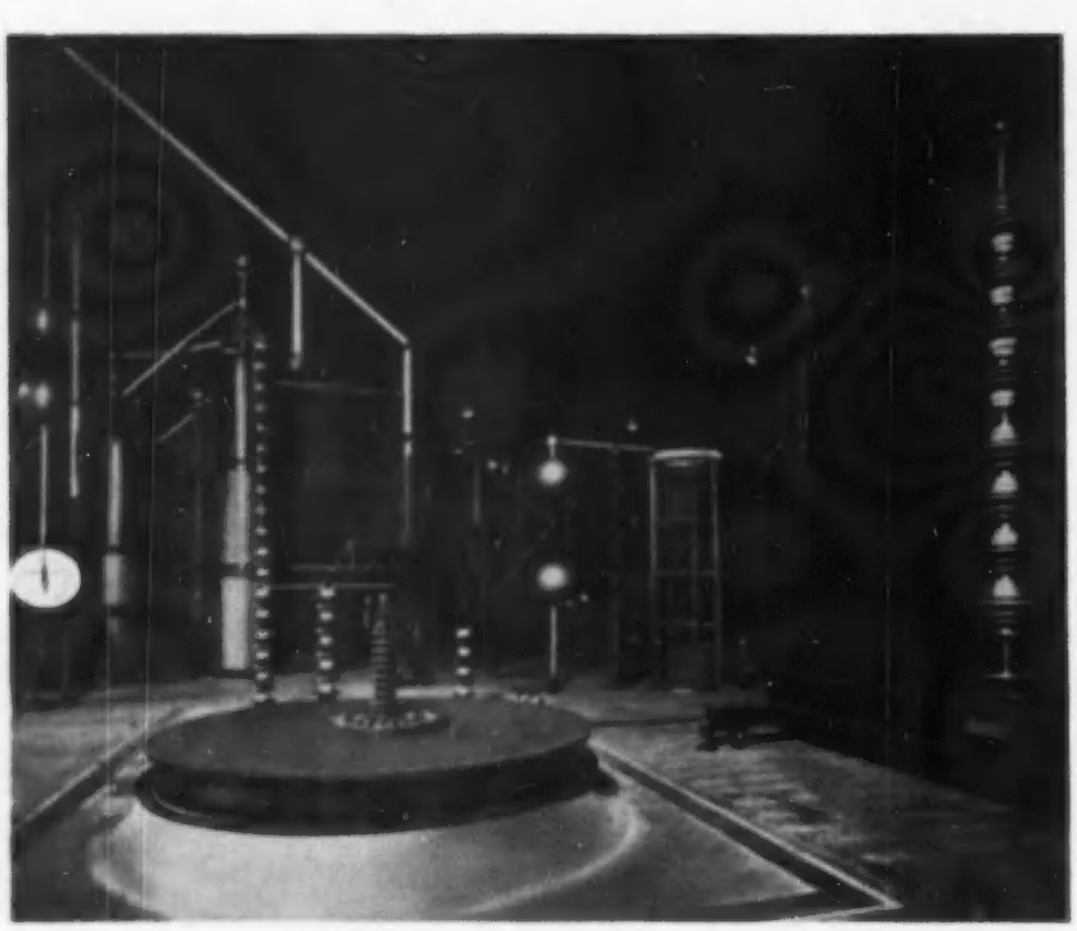


Fig. 3.—General view of High Tension Laboratory, Witton Works.

electrical and mechanical testing machine (fig. 4) which enables high voltage tests to be made on apparatus and material while under mechanical stress, and also a large heated oil tank for testing insulators while immersed in oil at any temperature. The oil tank is seen in the foreground of fig. 3.

It is the purpose of this article to discuss some of the problems involved in the testing of 132 kV apparatus based on the work which is being carried out in the High Tension Laboratory.

PORCELAIN INSULATION.

Porcelain plays a most important part in the insulation of all transmission lines. In the British Grid System it constitutes the entire insulation of the lines themselves and of all the exposed insulation in the substations. Figs. 5, 6 and 7 illustrate such insulators. Great improvements have taken place in the chemical composition of porcelain, giving it remarkable mechanical strength and extreme electrical resistance. These advances are due to the work of the ceramic industry and cannot be dealt with here. Electrical engineers however can claim much of the credit for the development of the shape of the insulators and the methods by which they are mechanically secured, both of which are essential for the proper application of porcelain to high voltage insulation.

The shape of a porcelain insulator is important for the following reasons. As a result of the advance which has taken place in the chemical composition of porcelain, the position may be said to have been reached where such an insulator never breaks down by a puncture through the material; a failure is always due to a flashover across the surface. The capacity to withstand surface flashover is a function of the shape of the insulator. When an insulator is subjected to a high voltage, electric stresses are set up between various parts of the surface of the insulator. The air in the immediate neighbourhood of these parts of the surface is subjected to the same electric stresses. If the top of the insulator be at, say, 76 kV above earth and the bottom at earth potential, the object of the designer is to secure as even a potential gradient as possible over the surface from top to bottom. In an imperfectly designed insulator the gradient is considerably steeper in one part than in another. If the steepness exceeds a certain figure the air in the neighbourhood is ionised and its insulation lowered. This may spread and cause the insulator to flash over. Figs. 8 and 9 show the results obtained with insulator strings comprising spring ring units manufactured by Steatite & Porcelain Products, Ltd., for the grid lines built by the G.E.C.

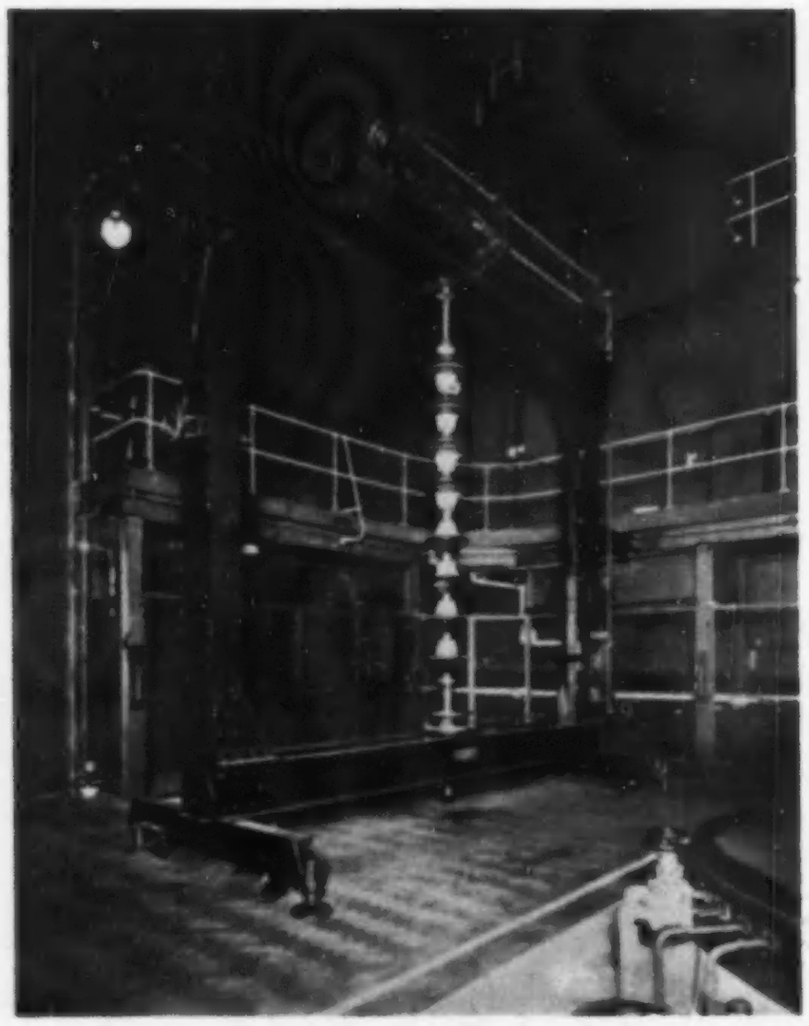


Fig. 4.—Combined electrical and mechanical stress testing machine.

For supporting high voltage transmission lines, above 33 kV, strings of disc insulators are

universally used. These are generally of the cap and pin type (fig. 10), in which the disc units are held on the one side by a metal cap which is cemented on, and on the other side by a suitably shaped pin fixed in a recess. Alternate pins and caps fit into each other, the whole forming a flexible chain of the length required. The so called spring ring insulator is of this general type. It embodies the great advantage

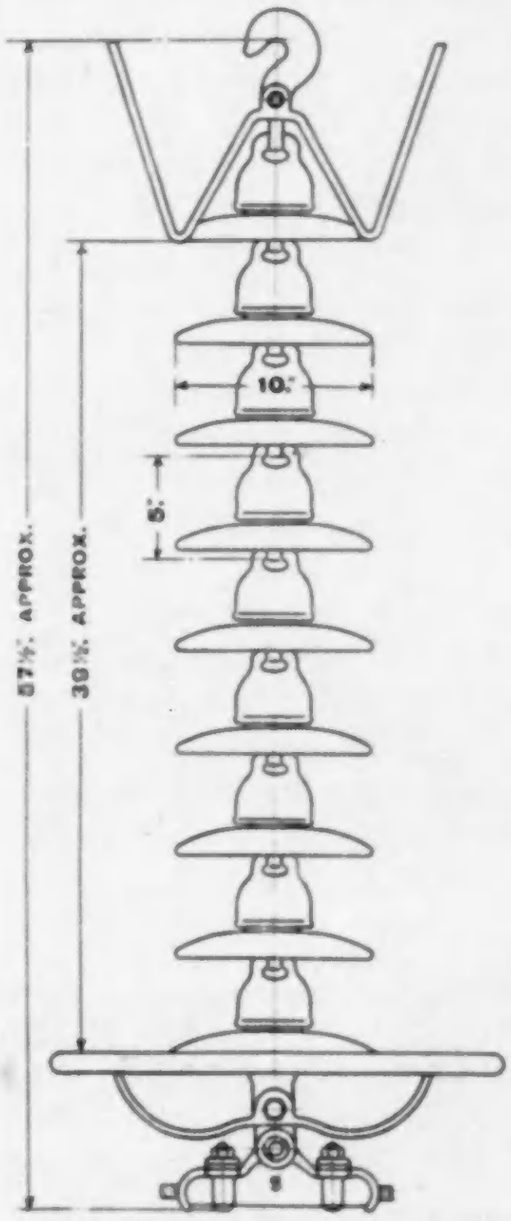


Fig. 5.—9-unit suspension string of spring ring insulators.

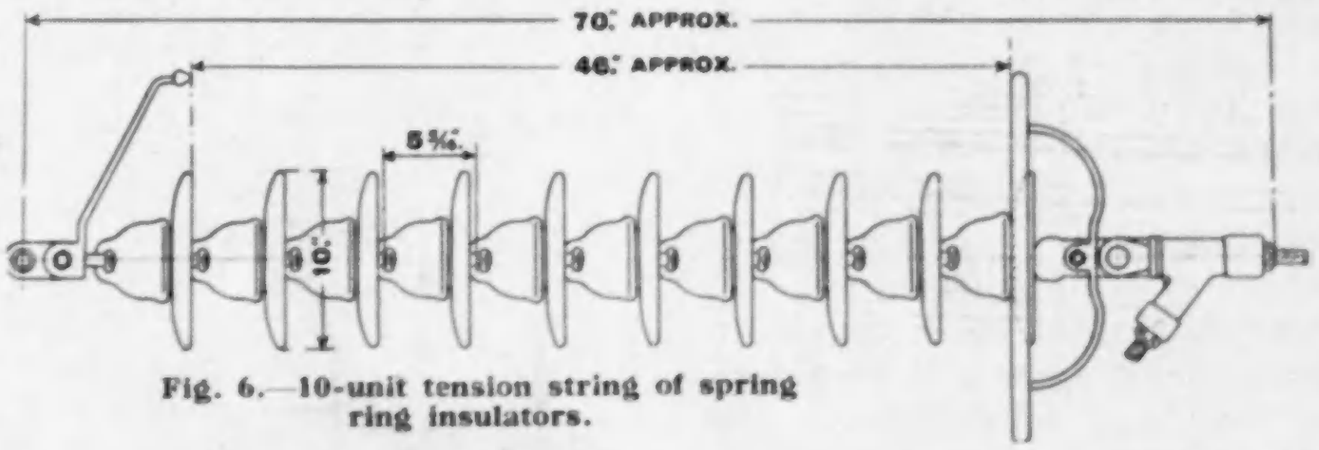


Fig. 6.—10-unit tension string of spring ring insulators.

that the pin is not fixed with cement. This not only results in considerably greater mechanical strength, but splitting of the porcelain, due to the unstable character of cement, is also entirely avoided.

Reference to fig. 10 will show that the dumb-bell shaped pin is held in the insulator firstly by a lifebuoy shaped spiral spring and secondly by a filling of metallic alloy. This construction has been patented and the British patent rights are held by the G.E.C.

POST INSULATORS.

A post insulator of the type used for the isolating links, etc., in the grid open air substations is illustrated in fig. 7. It is necessary that these posts should withstand certain specified mechanical pulls longitudinally, at right angles and torsionally, as well as simultaneous vibrations. A machine designed for testing post insulators for this purpose is shown in fig. 4, and

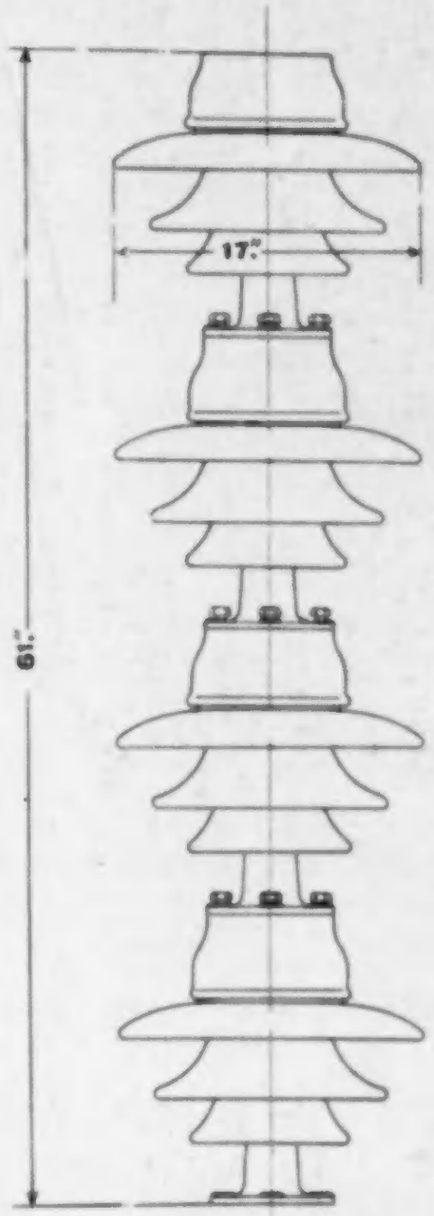


Fig. 7.—4-unit post type insulator, arcing horns not shown.

the posts themselves under test in fig. 11. The machine is of such dimensions that a high voltage, up to the flashover, can be applied to the posts while they are subjected to the mechanical stresses. It will be seen that two complete posts are arranged to pull against one another, the high voltage being applied to the centre point. It will also be noticed that this machine enables not only single units, as has been usual hitherto, but the complete post to be tested.

BAKELITE INSULATION.

The bakelite insulators used for very high voltage service consist of paper covered with bakelite varnish and rolled into cylinders. A special machine is used which covers the paper with bakelite varnish and dries it in one operation. The paper is then rolled

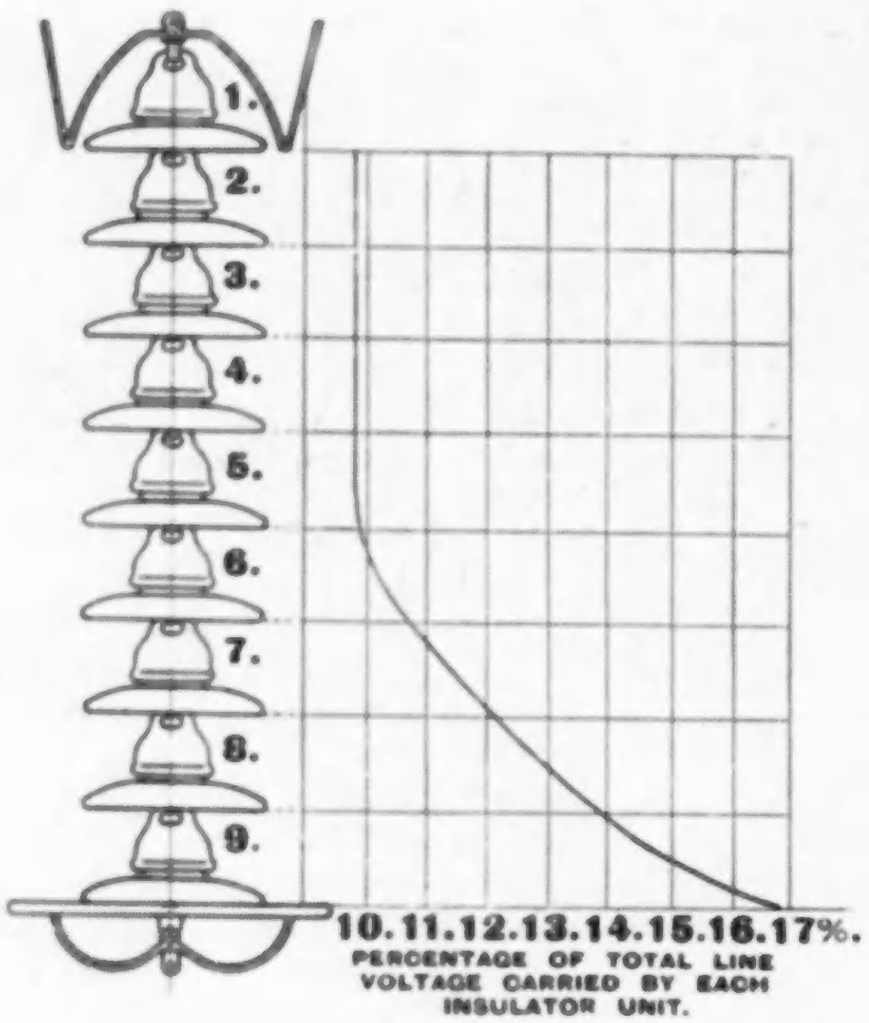


Fig. 8.—Voltage distribution over 9-unit suspension string.

round a mandrel to the required thickness, pressure and heat being applied in the process. At various calculated diameters layers of tin foil of varying lengths are inserted while the paper is being wound. These have the effect of causing a regular potential gradient to exist, when voltage is applied, both through the thickness of the material and along the outside surface of the bushing. Fig. 12 shows one of the machines employed for this class of manufacture.

After winding, the cylinder is placed in an oven and subjected to a prolonged heat treatment. This results in an allotropic modification of the bakelite whereby it is hardened and forms with the paper a homogeneous mass possessing remarkable mechanical and electrical properties.

A complete bushing made on these lines as used in a 132 kV oil circuit breaker is illustrated in fig. 13, and the fall of potential along the surface of the bush is given in fig. 14. In fig. 13 the bakelite paper bush is seen enclosed in outer porcelain shroudings, the upper one being suitable for exposure to the weather and the lower one for immersion in oil. The two are held by a metal housing which is adapted to contain the current transformers.

HIGH VOLTAGE TESTS AT NORMAL FREQUENCY.

The scheme of connections of the cascade-connected testing transformer, illustrated in fig. 1, is given in fig. 15. This construction is the subject of the Dessauer patent, the British rights of which are held by Messrs. Ferranti Ltd. The object of this construction is mainly to avoid the use of very high voltage bushings and to reduce the voltage between windings, and between windings and the core and tanks of the individual transformers. Each

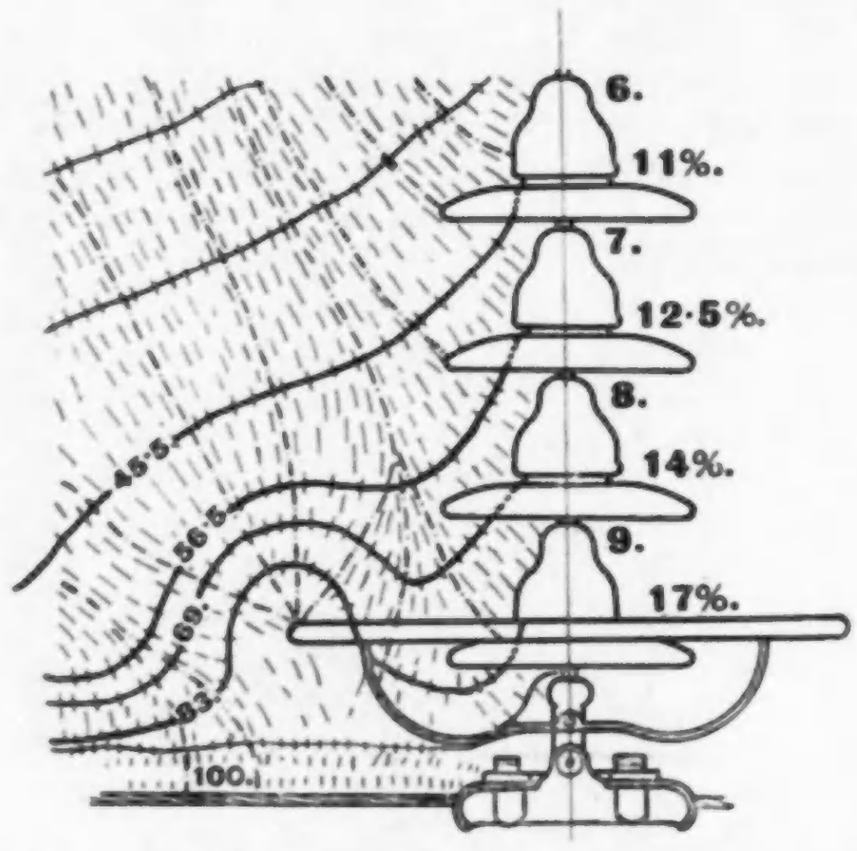


Fig. 9.—Lines of electrostatic force and equipotential surfaces on lowest four insulators of a 9-unit suspension string equipped with guard ring.

transformer has a normal high tension voltage of 250 kV, thus giving 750 kV with the three in cascade. The insulation is such that they will withstand with safety a voltage 33⅓ per cent. greater than this so that a total of one million may be obtained. It will be seen that the

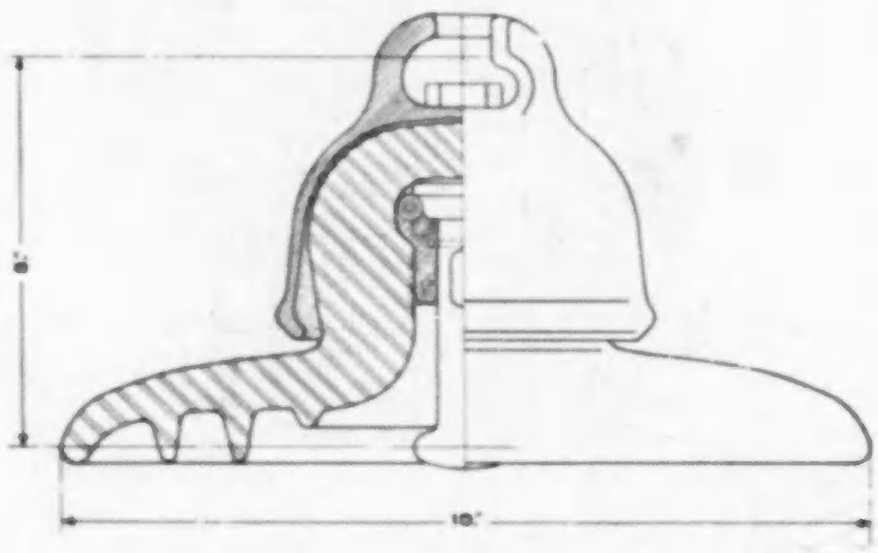


Fig. 10.—Spring ring insulator of the cap and pin type.

three transformers are insulated in various degrees from earth by standing on massive bakelite cylinders. The mid points of each winding are connected to the insulated tanks. Thus these latter, supposing a

total voltage of 1,000 kV is being generated, are respectively above earth potential by 167 kV, 500 kV and 833 kV. It will further be seen that under these conditions the individual transformer bushings are only subjected to a voltage of 167 kV, and can therefore be relatively smaller and less costly. Likewise, as the three transformers are precisely alike, they constitute spares for each other in the event of accident to one of them. The windings are auto-connected, tappings from each lower transformer exciting the one next higher to it. Equalising windings are provided which result in improved regulation and lower impedance. The whole bank is capable of giving an output of 100 kVA for two hours and the impedance of the entire combination, based on a load of 100 kVA, is 6·75 per cent. This impedance is low for such a voltage and thus a large energy output is assured. Figs. 16 and 17 show flashover tests made with this transformer at 50 cycles per second.

Fig. 11.—Simultaneous mechanical test and dry flashover at 500 kV, 50 cycles on four units of a post type insulator (without arcing horns).

SURGE TESTS.

In addition to high voltage tests at normal periodicity (50 cycles per second) it is necessary to test insulators as to their capability to withstand the application of electric surges or impulses. The surge generator installed at Witton consists of a number of electrostatic condensers arranged upon the Marx principle, *i.e.*, they are charged in parallel through vacuum rectifying valves, and discharged in series. Thus considerably higher discharge voltages

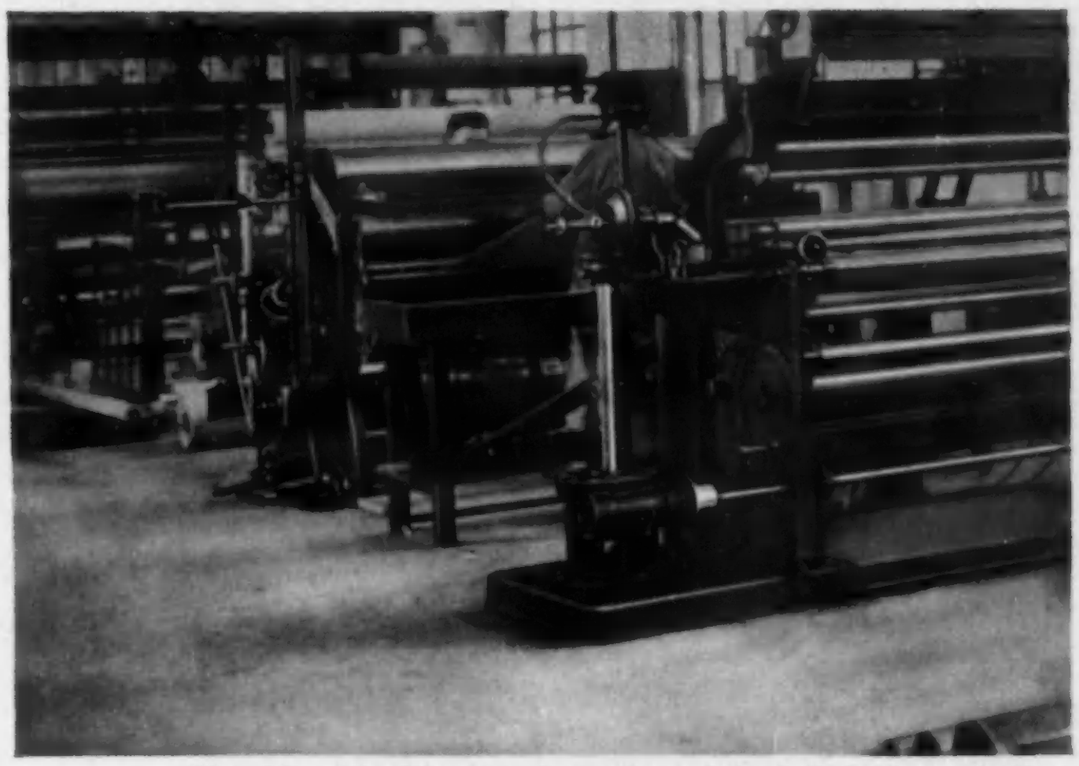


Fig. 12.—Machine for insertion of tin foil during winding of paper for bakelite bushes.

(up to one million volts) can be obtained than the voltage required to charge the surge generator itself. The diagram of connections is given in fig. 18.

The standardization of surge tests in the various industrial countries has not yet proceeded very far. The V.D.E. rules of Germany only specify that the electrostatic capacity of the surge generator shall be at least 0.001 μF (900 cm). but are silent as to the shape of the curve. Peek (*Journal Am.I.E.E.*, Oct. 1930, page 871), recommends the standardization of two waves having wave fronts of .5 and 1.5 microseconds and 5 and 40 microsecond tails (time to drop to half crest voltage) respectively. Such tail lengths are very short as compared with those used by some insulator manufacturers whose tables are based on surges of time constants of 1,500 or 2,000 microseconds. (See *Mitteilungen der Hermsdorf Schomberg Isolatoren, Heft* 53/54, 1930—p. 1,700, etc.). The surges last referred to are generated by a generator working on the Marx principle. The wave front of such a surge, created by condensers discharging through a non-inductive resistance (*i.e.*, no definite reactance), is somewhat indefinite, depending as it does on the space arrangement of the connections of the generator. It is in any case very short, not exceeding one microsecond, and as short as that of any travelling wave due to lightning in a transmission line that has as yet been measured. Comparisons made between the results of Marx surge generators in different laboratories yield equal results, so that for most surge investigations the scheme shown in fig. 18 is all that is required.

IMPULSE RATIO TESTING WITH SURGE GENERATOR.

The impulse ratio of an insulator is the ratio of its breakdown voltage when tested with a surge to the breakdown voltage when tested with a 50 cycle current. If a condenser of capacity C farads, charged to the voltage E, be discharged through a non-inductive resistance R ohms, the discharge voltage falls according to the logarithmic law—

Discharge voltage $= E\epsilon^{-\frac{t}{CR}}$, t being time in seconds from the commencement of the discharge. The curves in fig. 19 are those corresponding to a condenser of 2,500 micro micro farads (*i.e.*, $2{,}500 \times 10^{-12}$ farads) discharging through one megohm.

In such discharges the time taken to fall to .37 of the initial voltage is always the same, no matter what the initial voltage may be. This time is called the time constant and is equal to CR seconds. In the case considered above the time constant is $2{,}500 \times 10^{-12} \times 10^{6} = 2{,}500$ microseconds.

Let us consider the case of an insulator being tested whose breakdown voltage (at 50 periods) is 500 kV and whose minimum impulse ratio is 1.5. The impulse ratio must be defined as being based on a particular character of surge. Let the impulse ratio of the insulator be based upon a surge having a time constant of 2,500 microseconds, *i.e.*, the surges shown in fig. 19.

On testing the insulator on the surge generator (whose curves are shown in fig. 19) it will be found that the minimum surge to break the insulator down will be 750 kV. On applying such a surge to the insulator the voltage will be initially 750 kV and will fall along the thick line curve to the point A. At the point A the insulator will fail. The reason for this is that by the time A is reached, the energy which is necessary to cause the breakdown has been put into the insulator.

It is clear that no matter what amount of energy be put into the insulator, if the voltage be lower than the horizontal line through A, breakdown will not occur. On the other hand if sufficient energy had been put into the insulator before the voltage had sunk to A, then the breakdown would have occurred at a higher voltage than A, and the measured surge voltage would not have been the *minimum* surge voltage which has to be determined.

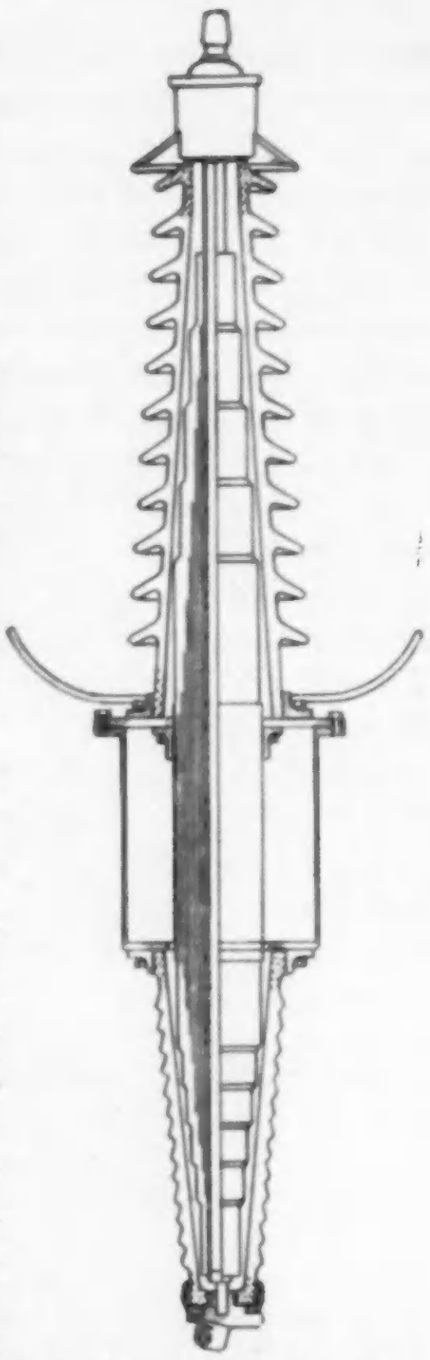


Fig. 13.—Bakelite bushing for 132 kV oil circuit breaker.

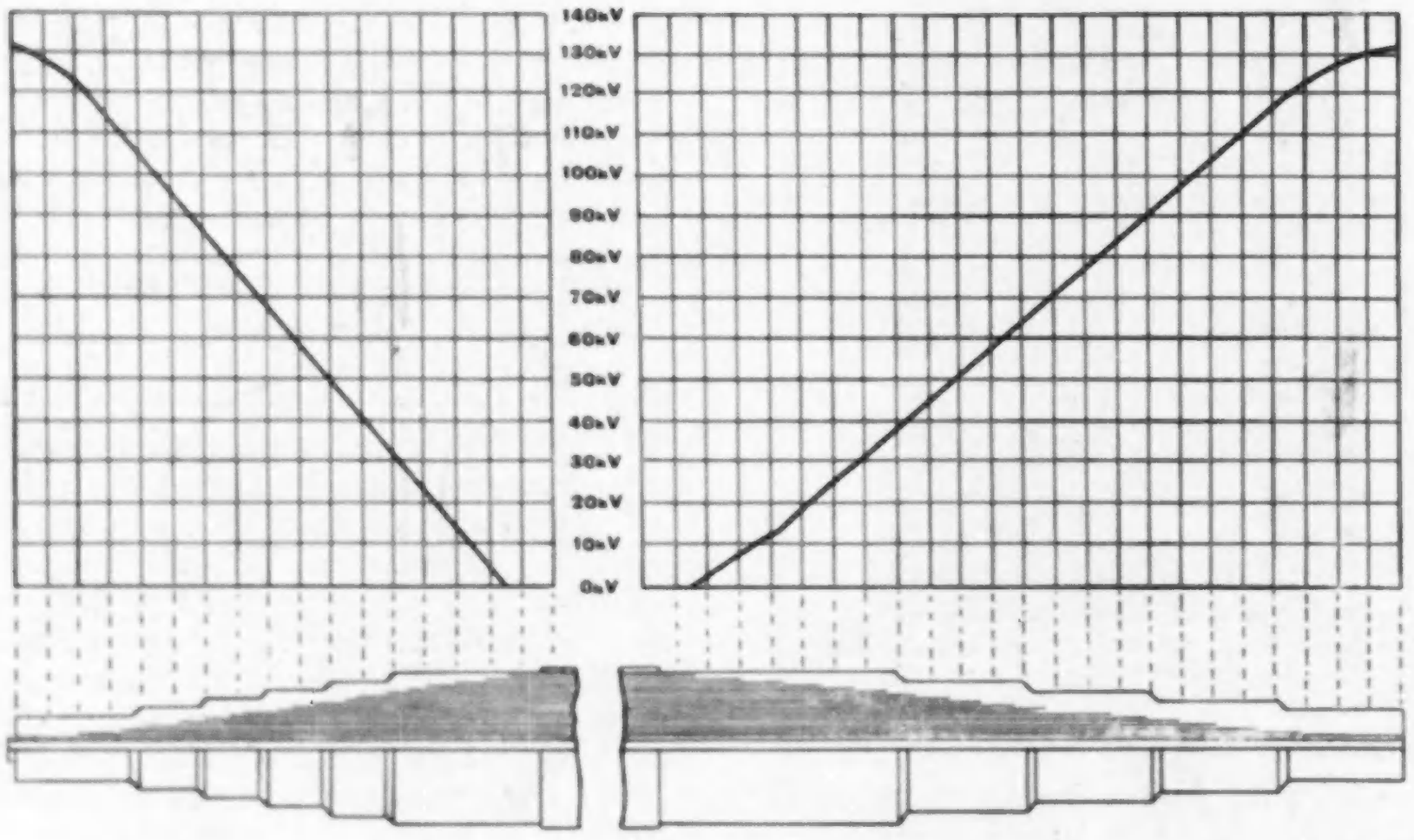


Fig. 14.—Fall of potential along surface of bakelite bush.

For example, suppose it be wished to find the impulse ratio of the insulation between turns of a transformer. All that is necessary is to take two pieces of copper, preferably circular in shape or

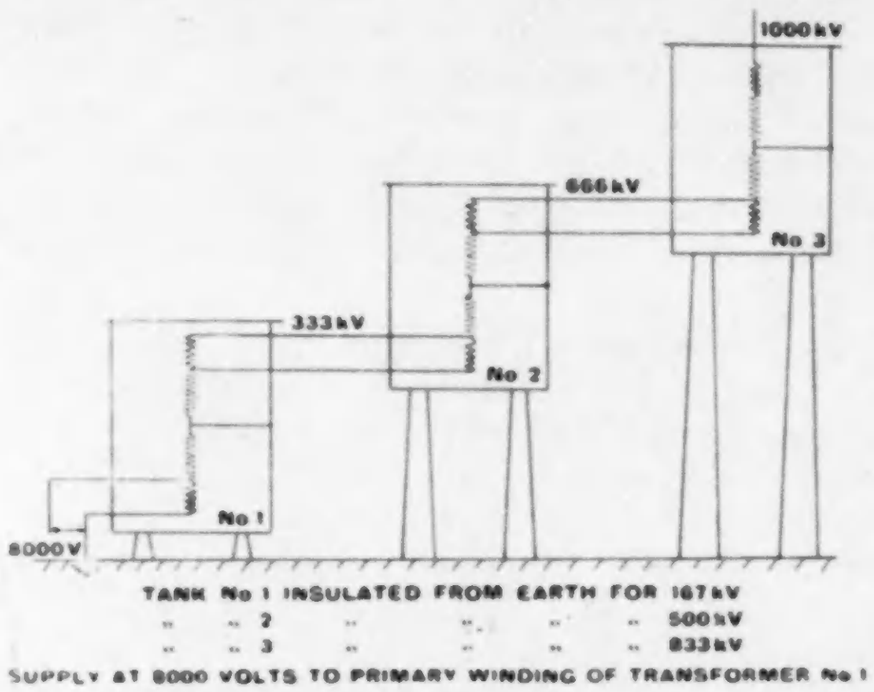

1000 kV
666kV
No 3
333kV
No 2
No 1
8000V
TANK No 1 INSULATED FROM EARTH FOR 167kV
" " 2 " " " " 500kV
" " 3 " " " " 833kV
SUPPLY AT 8000 VOLTS TO PRIMARY WINDING OF TRANSFORMER No 1

Fig. 15.—Scheme of connections of cascade connected testing transformer.

the same shape as the transformer coil, and insulate these from each other by the turn insulation. The impulse ratio can be determined at once as described above.

It is of course necessary to make sure that the object being tested does not upset the surge generator to such an extent as to render the results unreliable. This point is next discussed.

Electrostatic Capacity of the object being tested.

The electrostatic capacity of the object being tested is in parallel with the discharge controlling resistance. Theoretically therefore it affects the shape of the discharge curve. If it can be established that the effect is negligible, reliance can be placed upon the tests.

The capacity of a 132 kV bush is about 200 centimetres (say 220 micro-microfarads). This capacity is less than 10 per cent of the capacity of the surge generator under consideration (2,500 micro-microfarads).

During the first few microseconds of the passage of the test surge, a portion of the surge passes into the test object to charge it. This will have the effect of chopping off the top of the surge in proportion to the ratio of the capacity of the test object to the capacity of the surge generator. With the test object considered (*i.e.* a bushing) the error would be less than 10 per cent. With line and post insulators the error due to this cause would be very much less and quite negligible.

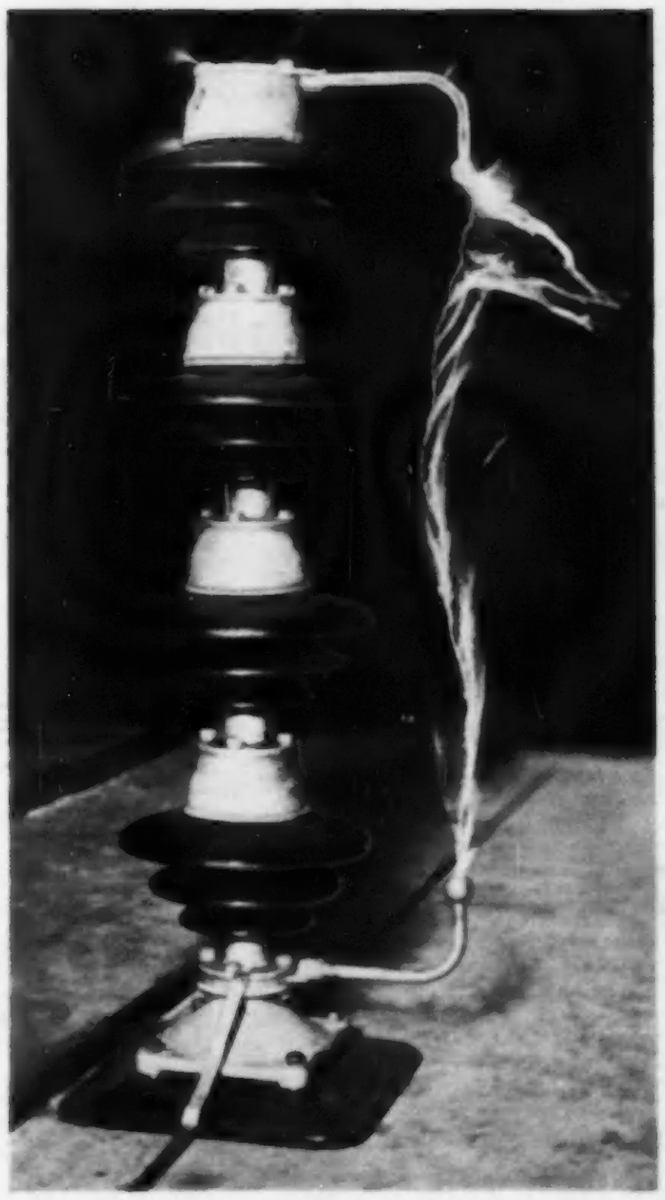


Fig. 16.—Dry flashover at 480 kV, 50 cycles on 132 kV post insulator showing protective value of arcing horns.

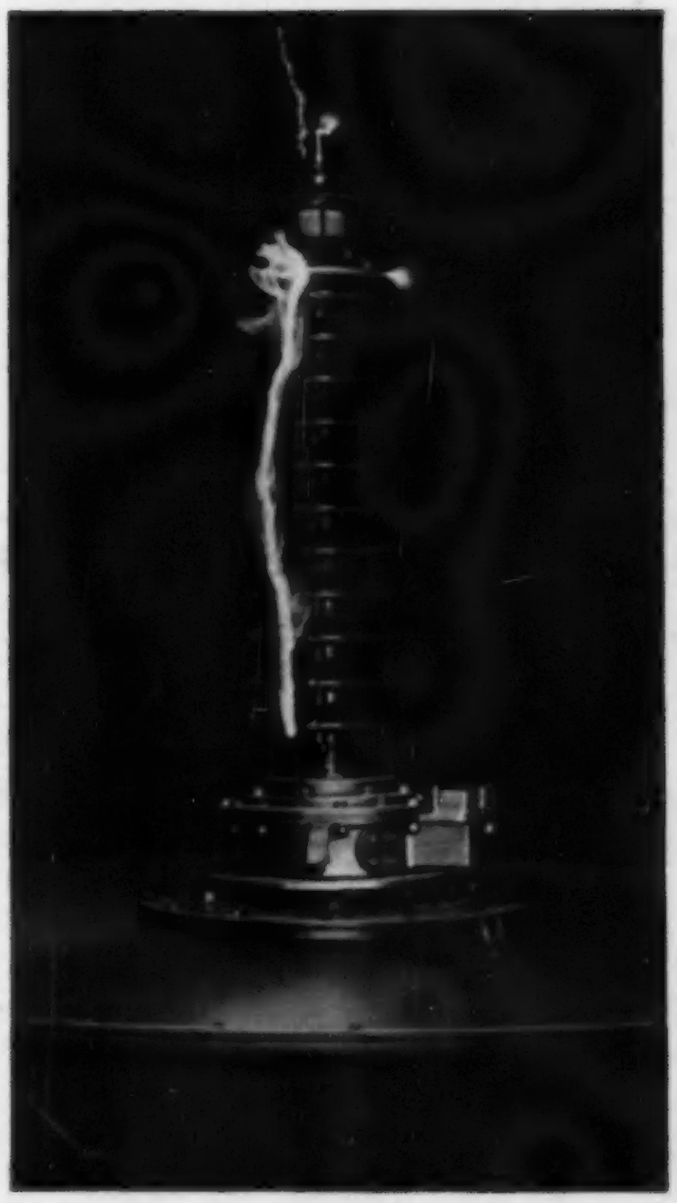


Fig. 17.—Dry flashover at 385 kV, 50 cycles on 66 kV bushing, lower end immersed in hot oil.

Effect of the Charging Resistances.

Another possible source of error is the resistances used to charge the condensers of the surge generator. A portion of the discharge surge will pass through these which are in effect (*i.e.*, their resultant) in parallel with the main discharge controlling resistance.

In the case considered above, therefore, this latter resistance would be somewhat greater than one megohm. The effective value will then be one megohm due to the parallel connection of the charging resistances.

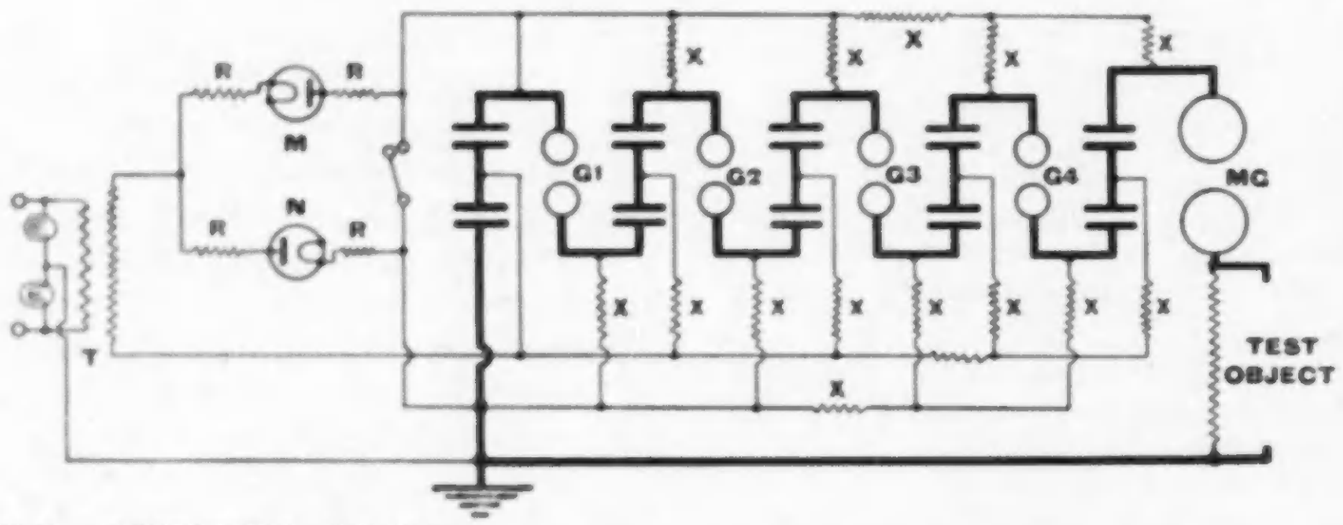
$$\frac{E}{2} = \frac{E}{e^{\frac{t}{CR}}}$$

t now being the time for the surge to sink to $\frac{E}{2}$ *viz.*, half the peak value.

Whence $e^{\frac{t}{CR}} = 2$

$$\therefore \frac{t}{CR} = \log_e 2.$$

and $t = .69\ CR$



M,N — RECTIFYING VALVES.
X — CHARGING RESISTANCES (1 MEGOHM WATER RESISTANCE).
R — VALVE PROTECTIVE RESISTANCES.
MG — DISCHARGE GAP.
DISCHARGE CONTROLLING RESISTANCE IN PARALLEL WITH TEST OBJECT.

Fig. 18.—Connections of surge generator.

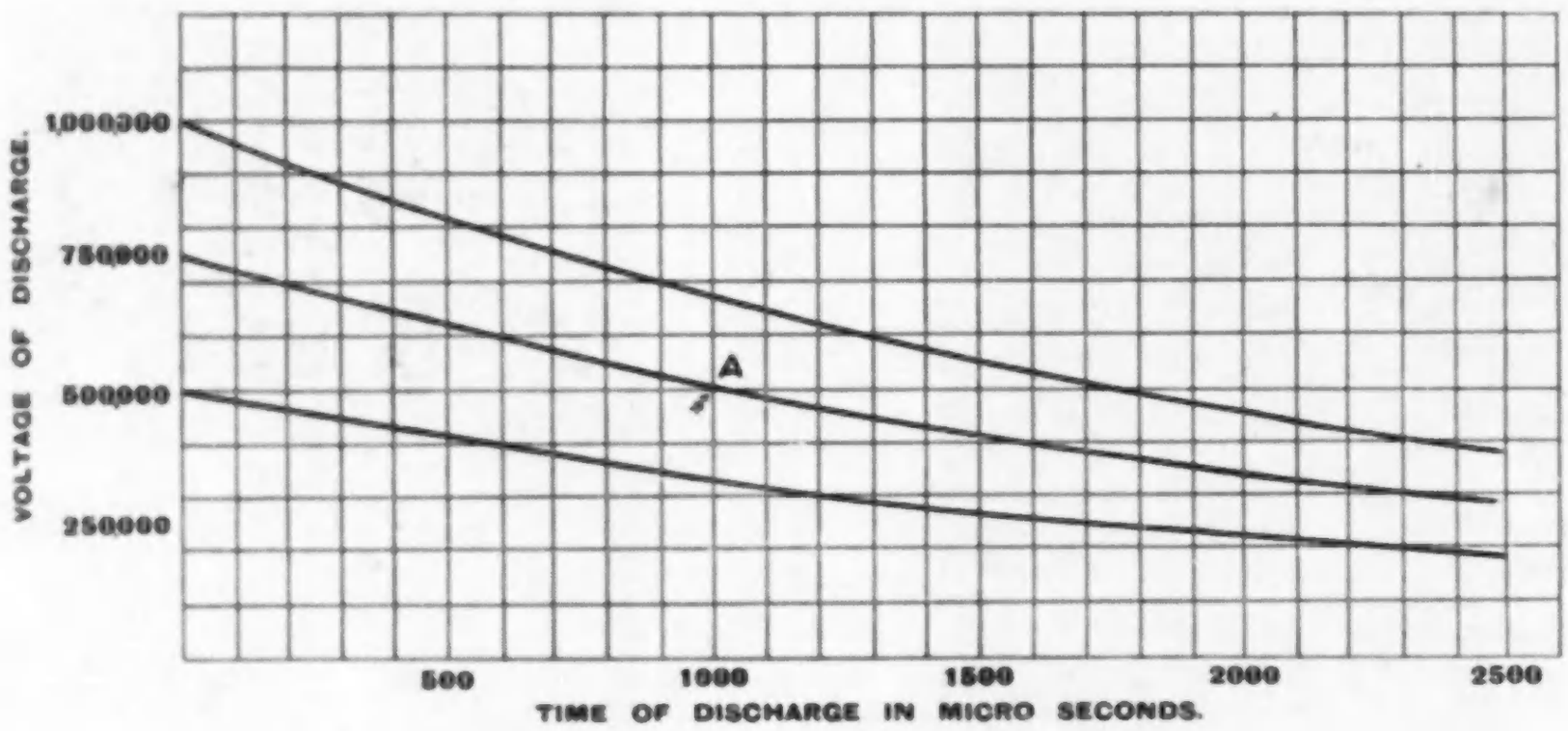


Fig. 19.—Curves illustrating surge discharge.

Comparison Between Different Methods of Defining the Shape of Surges.

As stated above, the impulse wave shape is sometimes defined as one in which the tail falls to half the peak value in a certain time, say in 20 microseconds, which is, for example, the value adopted by the Punjab Public Works Dept. The value of discharge controlling resistance, which controls the wave shape, required to secure such a wave, using a surge generator having 2,500 micro-microfarads capacity, may be calculated as follows :—

If t be 20 microseconds, then using the above surge generator the discharge resistance must be 11,600 ohms. With such a value of discharge controlling resistance the effect of the charging resistances within the surge generator is entirely negligible.

HIGH FREQUENCY TESTS.

It is of course well known, especially as a result of experience with wireless telephony, that the behaviour of insulating materials under the influence of high frequencies is altogether different from that

under normal frequency (50 cycles). Insulation can be perfectly satisfactory for the latter but entirely useless for the former. The reason for this is the higher internal loss at the high frequency due to electrostatic hysteresis. When an insulation material is subjected to a cycle of electrostatic strain (as occurs with every alternation of the testing voltage) it suffers a slight absorption of power. At 100,000 periods per second at equal voltage, this is naturally some 2,000 times as much as on 50 cycles per second. If the loss per cycle therefore exceeds a certain value

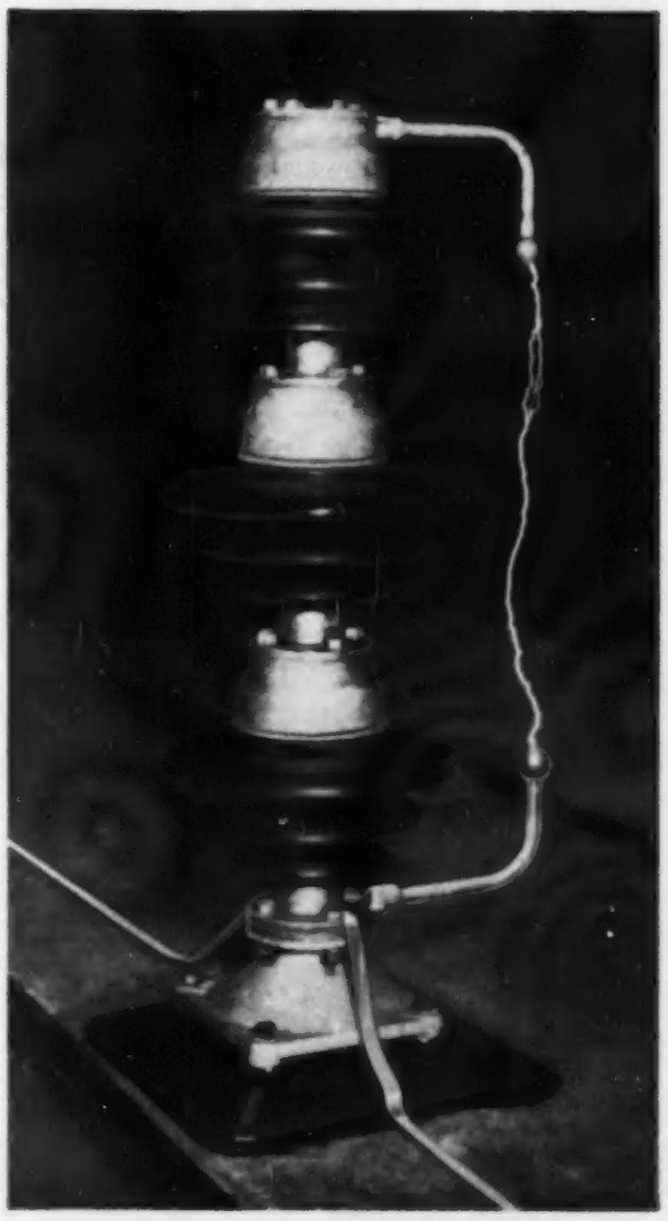


Fig. 20.—Surge flashover on a 3 unit post insulator at 700 kV (max.).

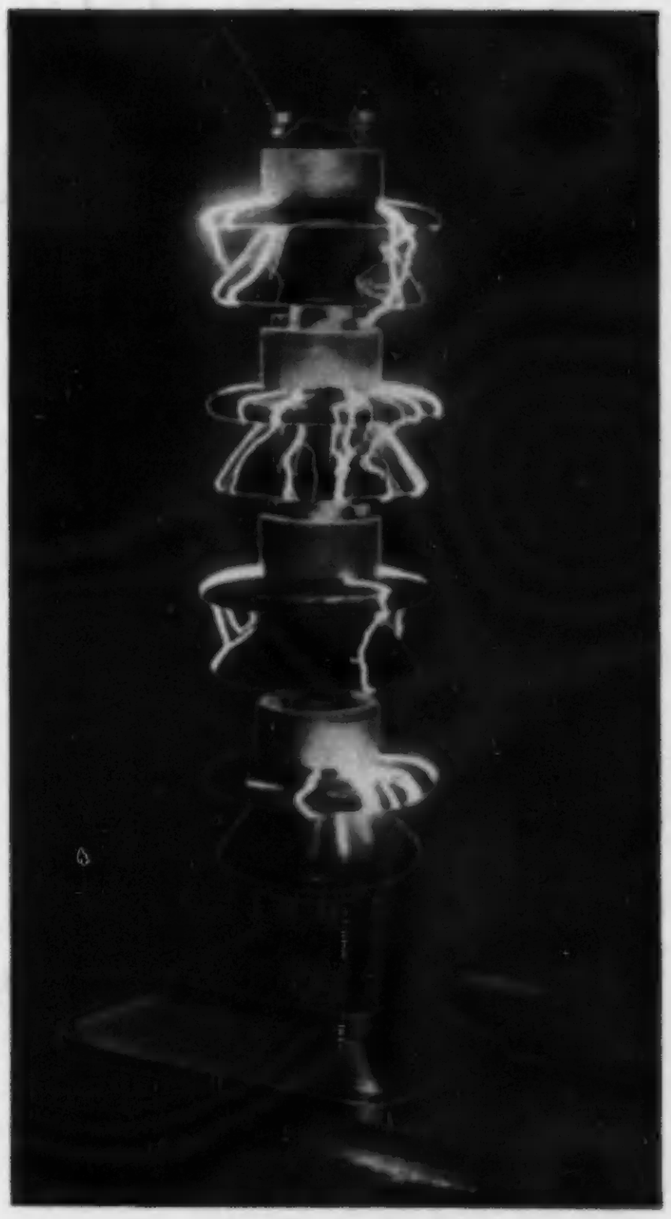


Fig. 21.—Surge flashover on small unit post type insulator at 700 kV (max.) with arcing horns removed.

the heat generated within the insulation which is cumulative will result in final failure. Moreover, the extra losses themselves, apart from the eventual failure of the insulation, may prevent the proper functioning of the apparatus; in other words, a bad high frequency insulator does not act as an insulator on high frequency at all.

High frequency tests are very useful when applied to composite insulators—for example, compound filled porcelain bushes. Air voids in the compound can be detected by these means.

High frequency tests are made by allowing the high frequency to discharge across the insulator under test for a certain period of time. It is therefore not generally necessary to measure the value in volts of the high frequency current although this can be done, if desired, by means of a sphere measuring gap. It is usually, however, only required to make sure that the frequency is, say, above 100,000 per second. This can be done by calculation from the dimensions of the testing generator.

The high frequency generator installed at Witton is shown in fig. 2, and the simplified diagram of connections in fig. 24. It consists of an air core Tesla transformer. The primary coil, of V shaped cross section, is fed at 50 cycles through a condenser and an arc, the latter being cooled by an air blast. By these means a series of high frequency damped trains are obtained, the successive trains following each other at the rate of 50 trains per second.

Examples of high frequency flashover are shown in figs. 22 and 23.

Frequency of Oscillation of High Frequency Generator.

From the diagram of connections of the high frequency generator given in fig. 24, it will be seen that the trigger gap is excited from a 50 period supply. As the voltage at each period rises from zero, at a certain value an arc forms across the gap. In the meantime the condenser C_1 has been charged to that value of voltage. The arc constitutes a short

circuit to the trigger gap so that we now have a closed primary circuit around which the condenser C_1 will discharge. This discharge will oscillate with a certain frequency.

C_1 C_2 are the capacities in farads of the condensers.

L_1 L_2 coefficients of self induction of the circuits in Henrys.

M coefficient of mutual induction between the primary and secondary windings.

C_2 is formed in part by the capacity of the secondary sphere gap and in part by the distributed capacity of the secondary coil, and further by the electrostatic capacity of the object under test. This last is small in comparison with the others and does not therefore have much effect.

The coils and values of capacity are so chosen that the primary and secondary circuits are in tune with one another. That they are in tune with one another is shown by the fact that a high secondary voltage is induced by resonance of the secondary with the primary.

Fig. 22.—High frequency flashover on 132 kV post insulator at 1,000 kV, 125,000 cycles.

Fig. 23.—High frequency flashover on small unit post insulator at 730 kV, 125,000 cycles, with arcing horns and ring removed.

Calculation of frequency of the induced secondary voltage.

In any closed circuit we can write an expression for the total voltage around it, the sum total of which is naturally equal to zero. The total voltage round the primary circuit at any instant is made up as follows :—

i_1 being the instantaneous current flowing.

(*a*) The ohmic drop $= i_1 R_1$

(*b*) The drop due to the self induction $= L_1 \frac{di_1}{dt}$

(*c*) The drop due to mutual induction with the neighbouring circuit which carries a current equal to i_2

$$\text{This drop} = M \frac{di_2}{dt}$$

(*d*) The drop across the condenser which can be calculated as follows :—

The quantity of electricity in a condenser is equal to the current which has flowed into it multiplied by the time the current has flowed. But the

current which flows into the condenser varies with time. The quantity of electricity which flows into the condenser in a very short interval dt of time immediately before the moment we are considering is i_1dt. The total which has flowed in from the

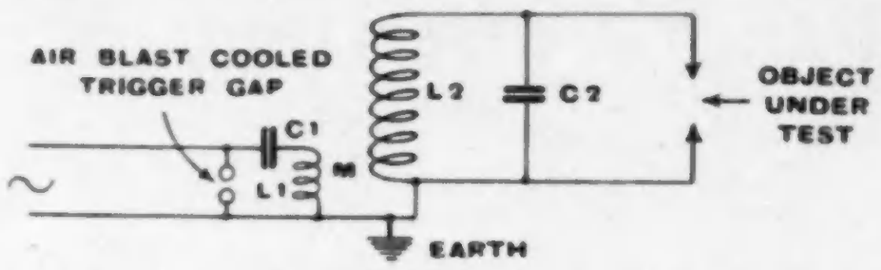


Fig. 24.—Diagram of connections of high frequency generator.

moment when the potential across the condenser was zero is the integrated value of i_1dt expressed mathematically $\int i_1dt$. At the moment we are considering, let the drop across the condenser be the value e_{c_1}, then the charge of the condenser is $C_1e_{c_1}$ and this equals

$$\int i_1dt \text{ ; therefore } C_1e_{c_1} = \int i_1dt$$

Therefore drop across the condenser is

$$e_{c_1} = \frac{1}{C_1}\int i_1dt$$

As stated above the sum of a b c and d must be equal to zero. Further i_1R_1 and i_2R_2 are negligible compared with other terms. Thus we obtain the two fundamental equations for the primary and secondary circuits, *viz.*:

$$L_1\frac{di_1}{dt} + M\frac{di_2}{dt} + \frac{1}{C_1}\int i_1dt = O \text{ ---------- (1)}$$

$$L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + \frac{1}{C_2}\int i_2dt = O \text{ ---------- (2)}$$

From these equations the following can be deduced mathematically, f being the frequency of discharge.

$$2\pi f = \sqrt{\frac{1}{C_1L_1(1 \pm k)}}$$

Where k = the coupling coefficient $= \frac{M}{\sqrt{L_1L_2}}$

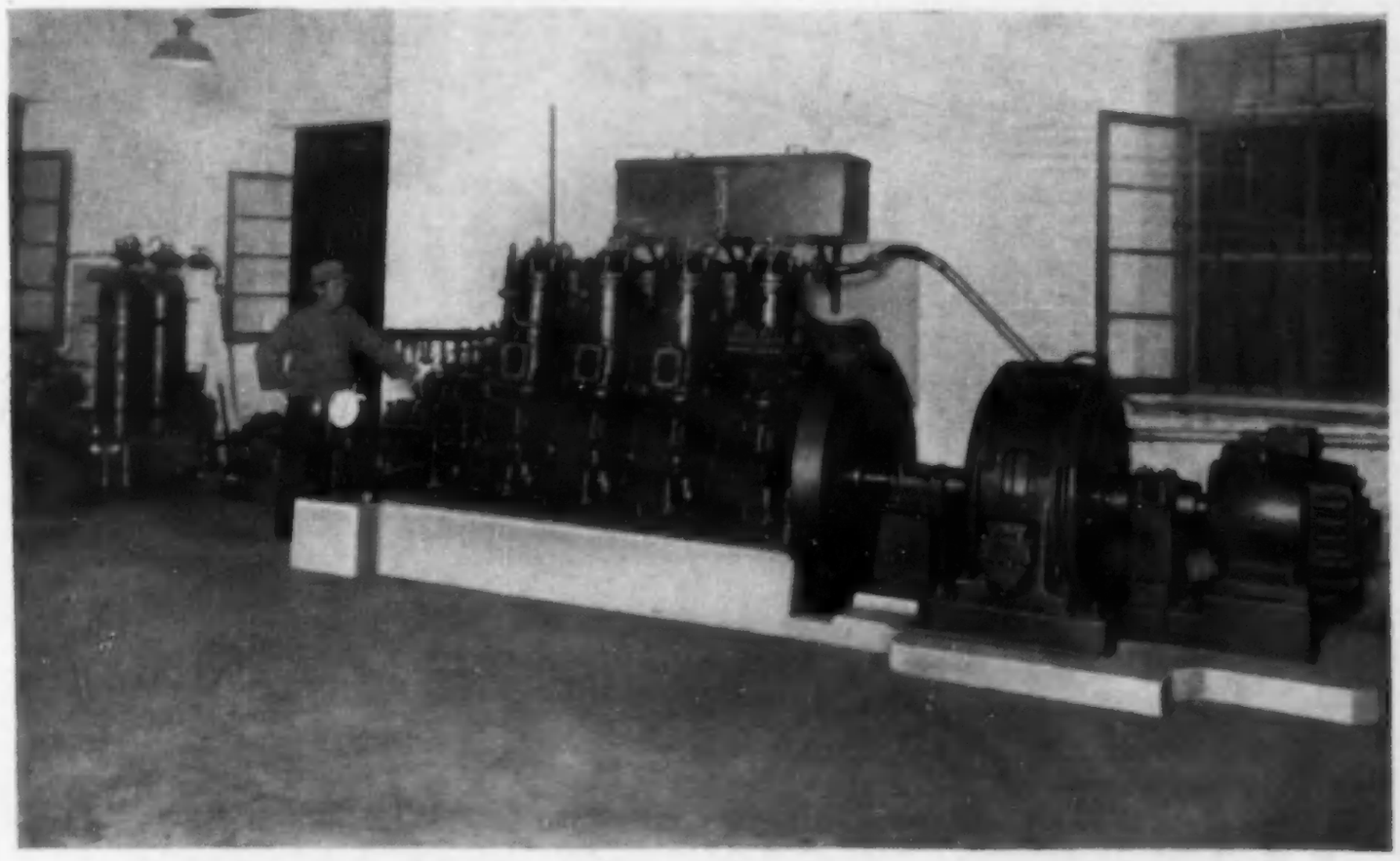
It will be seen that two frequencies exist in the circuit which are :

$$f_1 = \frac{1}{2\pi\sqrt{C_1L_1(1+k)}}$$

$$f_2 = \frac{1}{2\pi\sqrt{C_1L_1(1-k)}}$$

Now as $k = \frac{M}{\sqrt{L_1L_2}}$ and the mutual induction between the coils is small as compared with the square root of the self induction of the two coils multiplied together, k may be regarded as equal to zero and we have the frequency of oscillation of the primary circuit $= \frac{1}{2\pi\sqrt{C_1L_1}}$ the frequency of the secondary circuit being of course the same.

Diesel-Generating Plant in China.



One of the two 65 kW 400-volt, 60-cycle, 400 r.p.m. oil engine driven alternators supplied to the "Kwang-Ming Denki Kungssu" (Bright Light Electric Co.) of Weiheiwei, China.

Some Notes on Starting Motors for Rotary Converters.

By R. G. JAKEMAN, D.Sc., M.I.E.E.
Design Dept., Witton Engineering Works.

The author presents some interesting facts relating to the starting of rotary converters by A.C. motors having a smaller number of poles than the rotaries.

With the very general use of this method of starting, the design and efficiency of the two types of motor discussed, are matters worthy of consideration.

ALTHOUGH there are other methods of starting rotary converters, the use of an A.C. motor is very general, especially for the larger sizes of rotary converters. There are also various systems of winding and connecting the starting motor. These notes, however, are limited to the system in which the starting motor has a smaller number of poles than the rotary, and in which the motor is connected directly to the supply mains without any electrical connection to the rotary.

Two types of starting motor will be considered, namely (1) slipring motors with external resistances, and (2) motors with solid iron or steel rotors. The latter is subdivided into motors with (a) single and (b) double stator windings.

(1) SLIP-RING MOTOR WITH EXTERNAL RESISTANCE.

The external resistance in this case is fixed and permanently connected across the slip-rings. Its value should be such that the starting-motor will drive the rotary light at a speed slightly higher than the synchronous speed of the latter. For example, if the speed of the rotary is 750 r.p.m. (8 poles at 50 cycles), the starting-motor has 6 poles and a synchronous speed of 1,000 r.p.m., so that the external resistance has to be designed to give 25 per cent. slip at the correct load.

Let

W_o = light-running loss of the rotary at its synchronous speed.

s_o = slip of starting-motor at the synchronous speed of the rotary.

V_2 = open-circuit rotor volts.

I_2 = rotor current at starting.

I_o = rotor current when driving the rotary light at its synchronous speed.

R_2 = external resistance + resistance of rotor per phase.

We have

$$s_o = \frac{3I_o^2 R_2}{W_o + 3I_o^2 R_2}$$

and

$$I_o = \frac{W_o + 3I_o^2 R_2}{V_2 \sqrt{3}}$$

from which follows

$$I_o = \frac{W_o}{1 - s_o} \cdot \frac{1}{V_2 \sqrt{3}}$$

The loss in the resistance, when running,

$$= 3I_o^2 R_2 = W_o \frac{s_o}{1 - s_o}$$

Hence

$$R_2 = \frac{s_o (1 - s_o) V_2^2}{W_o}$$

By subtracting the value of the resistance of the rotor, we have therefore the value of the external resistance necessary for the starting-motor to run with a slip s_o at a load W_o.

We have further

$$I_2 = \frac{V_2}{R_2 \sqrt{3}} = \frac{W_o}{s_o(1 - s_o) V_2 \sqrt{3}}$$

and starting torque $= 3I_2^2 R_2$ synchronous watts, which, by means of the above equations, resolves into $W_o/s_o\ (1 - s_o)$ synchronous watts.

Hence, starting torque, expressed in h.p. at the synchronous speed of the rotary $= W_o/746 s_o$

This will, in the great majority of cases, be found to be more than sufficient to start the rotary. If it is not sufficient, the value of the resistance must be decreased, so that the slip will be reduced, with the result that it will be more difficult to self-synchronise.

The assumption has been made in the above that the flux is constant. This is admissible, because the resistance is so high compared with the reactance.

Since the rotor resistance is very high compared with the reactance, the torque is proportional to the slip and the torque curve is a straight line, shown by curve A in fig. 1.*

* Hawkins, Smith and Neville. Papers on the Design of Alternating Current Machinery, p. 315.

We have further, mechanical output, W, is proportional to $T(1—s)$ where T is the torque, and $W = L(1 - s)/s$, where L is the loss in the rotor circuit.

Hence, L is proportional to Ts.

The loss in the rotor circuit is therefore represented by curve B, and curve C represents the power available for driving the rotary light. Curves B and C are plotted as percentages, the loss in the rotor at standstill being taken as 100 per cent.

For a given value of resistance, the speed at which the rotary will run is obtained from curve C. After determining the power to drive the rotary light as a percentage of the loss in the rotor at standstill, the slip can be read off curve C.

(2) MOTOR WITH SOLID IRON OR STEEL ROTOR.

(a) With single stator winding.

The loss in the rotor can be determined by means of the method given by Rüdenberg* for finding the losses in solid pole-shoes due to the armature teeth.

Replacing t_1, the slot-pitch, by τ, the pole-pitch, we have for the loss per pole-pitch

$$\int_0^{\tau} dx \int_0^{\infty} dy \int_0^{l} dz \; \frac{v^2 B^2}{\rho \, 10^{12}} \; e^{-2\lambda y} \; \cos^2 \frac{\pi}{\tau} x$$

$$= \frac{v^2 B^2}{\rho \, 10^{12}} \; \frac{\tau}{2} \; \frac{l}{2\lambda} \text{ watts.}$$

The total loss over the whole rotor is therefore

$$\frac{v^2 B^2}{\rho \, 10^{12}} \; \frac{\pi D}{2} \; \frac{l}{2\lambda} \text{ watts,}$$

where v = peripheral velocity of the rotating wave in metres per second.

ρ = specific resistance of the rotor.

D = diameter of rotor in cm.

l = length of rotor in cm.

$\lambda = \frac{2\pi}{10^4} \sqrt{\frac{f\mu}{10\rho}}$

f = slip frequency in rotor.

μ = permeability of rotor.

B = max. gap density.

Further, since $v = \frac{f \pi D}{100p}$

$$\text{Total loss} = \frac{f^2 \pi^3 B^2 D^3 l}{p^2 \rho \, 10^{16} \, 4\lambda}$$

$$= \frac{f^{1.5} B^2 D^3 lk}{p^2 \, 10^{10}} \text{ watts,}$$

where $k = \frac{1}{25 \sqrt{\rho\mu}}$ and p = pairs of poles.

It is difficult to assign definite values to k which will suit all conditions, because μ varies considerably with the flux-density. An empirical value for k, however, can be obtained from tests.

It is found that the stator impedance drop may usually be considered as practically constant when starting and running, because although the current is lower when running, the power factor is also less. The result is that the density in the rotor may be taken as constant throughout the starting period.

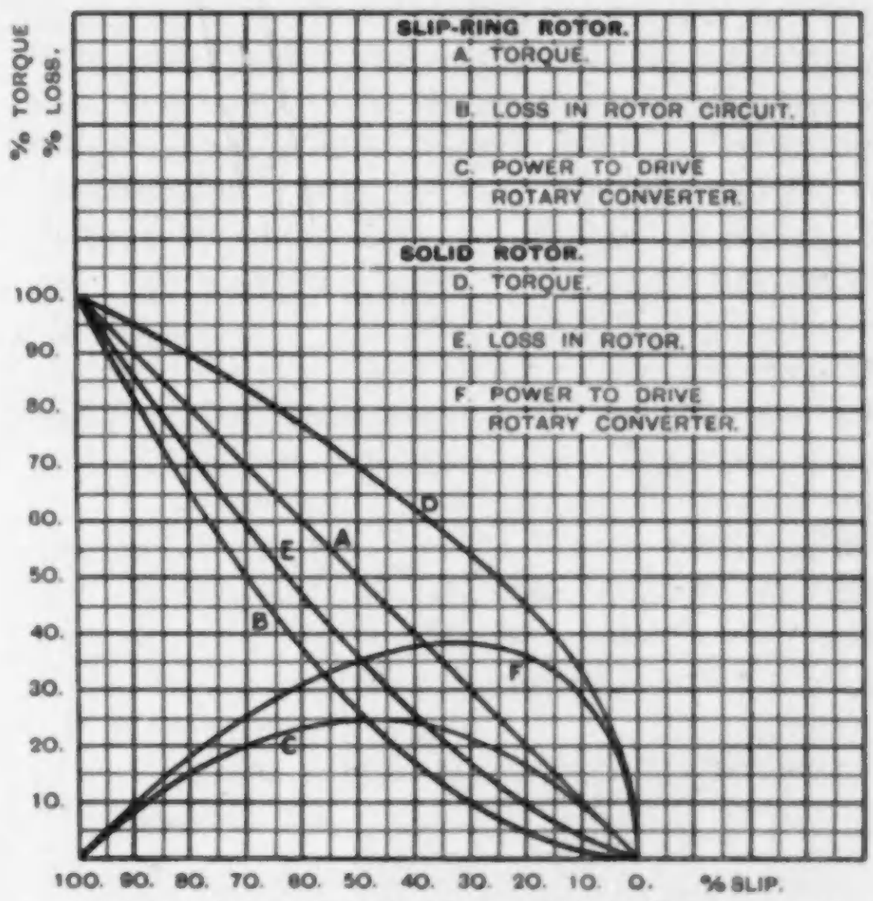


Fig. 1. Torque and loss curves for slip-ring and solid rotors.

It will be noted from the above equation that the loss varies with the 1.5 power of the frequency. In this connection it is of interest to refer to a curve for eddy-current brakes given by Rosenberg.*

Curve E in fig. 1 represents the loss in the rotor, taking the loss at rest as 100 per cent. This is plotted from the above equation, where the loss varies as the 1.5 power of the slip. Curve D is the torque and curve F the power available for driving the rotary light. The two latter curves are obtained from curve E by means of the relations, L is proportional to Ts and $W = L(1 - s)/s$.

REMARKS ON THE CURVES.

Several interesting points arise in connection with these curves. Take the case of a rotary converter with 16 poles and a synchronous speed of 375 r.p.m., having a starting-motor with solid rotor and 14 poles. The slip of the motor at 375 r.p.m. is then 12.4 per cent. Suppose the light loss of the rotary is 40 per cent. of the least rotor loss necessary to start the set. Referring to curve F, it is seen that at a slip of 12.4 per cent, the value 40 per cent. lies above the curve. The rotary will

* La Cour and Bragstad. Elements of Electrical Engineering, Vol. 1, p. 371.

* Journal I.E.E. Vol. 46, 1911, p. 450.

therefore not run up to speed because the loss in the rotor is too high.

To overcome this difficulty, it would be possible to increase the rotor loss at starting above the least value necessary. If the rotor loss at starting is increased to 130 per cent., the light loss of the rotary becomes 31 per cent. of this new value, and this point will be seen to lie on curve F.

Another way of dealing with the difficulty is to wind the starting-motor with 12 poles instead of 14. The slip of the motor at 375 r.p.m. is now 25 per cent. Denoting the least rotor loss to start the set with a 14-pole motor as 100 per cent., the least rotor loss with 12 poles will be 100 (14/12) = 117 per cent. and the light loss of the rotary will be 40 (100/117) = 34 per cent. Referring to curve F, it is seen that this value falls within the curve at 25 per cent. slip. The speed will therefore rise slightly above 375 r.p.m. so that synchronising is assured.

It will be noted that the power taken with the 12-pole motor is 117 per cent., as against 130 per cent. with the 14-pole motor.

Take now the case of a 25-cycle rotary converter running at 500 r.p.m., with 6 poles, having a starting-motor with 4 poles. The slip of the motor is 33.3 per cent. Now if the light loss of the rotary is 25 per cent. of the least rotary loss to start the set, this value falls well within curve F at 33.3 per cent. slip. The speed will therefore rise until the slip is about 20 per cent., according to the relation of the light loss to the speed. It is possible that this will make self-synchronising difficult.

It is seen, however, that the same value falls above curve C for a slip-ring motor. Hence, if a slip-ring motor is used, it is only necessary to increase the rotor loss at starting slightly and the motor will run the rotary up to the correct speed.

(b). Motor with solid iron or steel rotor, with double stator winding.

Another way to deal with the latter problem (6 pole rotary and 4 pole starting motor) is to wind the stator of the motor with two windings, one for four poles and the other for six poles, the two windings being connected in parallel. The result of this is that the motor can be arranged to run slightly above synchronous speed and that the speed is not so sensitive to changes in load or voltage as with the single winding.

On starting, both windings exert torque, but when the rotary reaches synchronous speed, the winding with the higher number of poles has no effect, being in synchronism. Above this speed, the winding with the higher number of poles acts as an induction generator and exerts a torque opposing the motoring torque exerted by the winding with the lower number of poles. The higher the speed, the higher the generating torque and the lower the motoring torque, so that there is a strong tendency to run very close to the synchronous speed of the rotary.

Road Transport in Madeira.

Recent additions to the generating plant of the Madeira Electric Light Co., include a 750 h.p. Fraser & Chalmers heavy oil engine. The transport employed to haul the 12 ton flywheel to site, consisted of teams of oxen.

The Mass Production of Incandescent Electric Lamps.

A Specialised Factory.

By G. CHELIOTI
Works Manager, Osram-G.E.C. Lamp Works.

AS originally planned, this article was to have been a simple description of a new factory recently built by the G.E.C. at North Wembley for the mass production of incandescent electric lamps. It was felt that, though the building and its equipment were designed for a highly specialised purpose, the subject might hold much of interest to those not directly concerned with the manufacture of lamps. The author has, however, found his task much less straightforward than it appeared at the outset and, though still endeavouring to deal with the general problems of mass production rather than the particular ones of the lamp maker, he has been forced or tempted into many digressions beyond the originally intended limits in the desire to present a clear picture of all that is involved in the new undertaking.

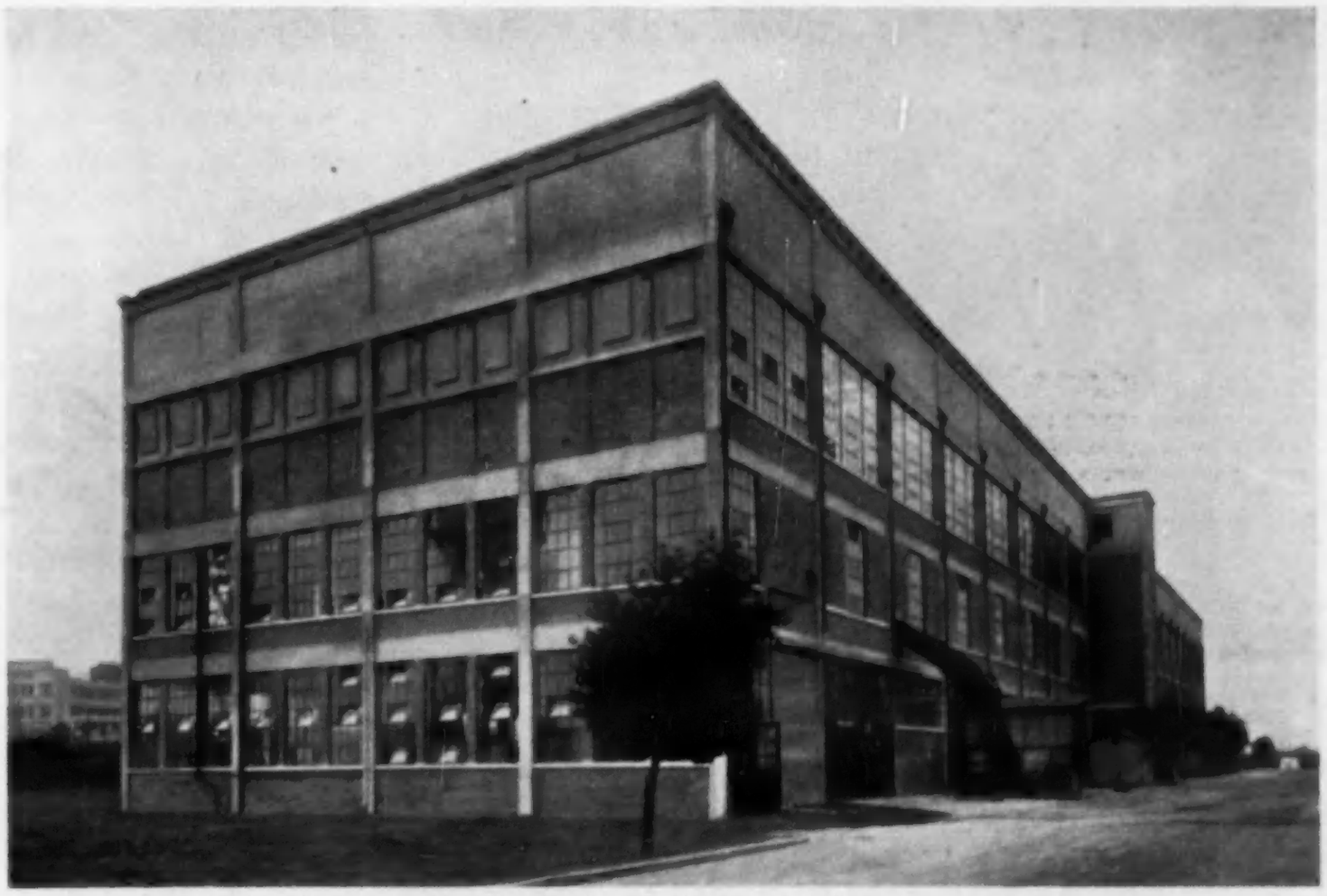


Fig. 1.—General view from the south-east of the new Osram factory.

MASS PRODUCTION.

At the outset, what are we to understand by the term "mass production"? Though the British public learned during the war to use the name and to respect the thing it denotes—and naturally enough since, applied to the provision of munitions, it literally saved the situation—it has suffered in peace-time the fate which proverbially overtakes the soldier in like circumstances, and has fallen somewhat into disrepute. Not only has it been widely, if not always wisely, attacked on aesthetic or humanitarian grounds, but astute advertisers, scenting a favouring wind and exalting their goods as "not mass produced," have done further mischief until, to the man in the street, the words "mass produced" have come to mean much the same as "cheap and nasty."

When we analyse the genuine objections, however, we find the kernel to be that goods so produced lack individuality. While we may freely grant that this is so and that it is a serious drawback in some cases—who would wish, for example, to dress and to furnish his house exactly like his neighbour?—it is true also that in articles of pure utility, uniformity is a shining virtue. Mass production, precisely because it demands and ensures the closest uniformity in the product, is the best possible system in such cases, not only on economic but on all other grounds. But even if we decide to ignore

any unsavoury associations it may have acquired, and to use the term in its original and strictly technical sense, we have still to define it, for even among engineers there seems to be considerable vagueness as to its exact meaning and limitations.

As exemplified in the new Osram-G.E.C. Lamp Works it signifies an organization for the continuous output of identical articles by machines designed for that especial purpose, the building being exactly adapted to accommodate the flow and storage of raw materials and finished goods, and every worker specially trained in his or her particular operation. In this sentence is summed up the aim which guided the design of the whole factory from ground plan to the last detail of equipment, and if it be accepted as an adequate definition, some interesting consequences can be deduced which sharply differentiate such an establishment from one not truly engaged in mass production. For instance, whereas in a non-specialised factory the designer and his satellite draughtsmen are omnipotent, the workshops being powerless until each order has been translated into blue-prints, to the mass producer change in the design of the product is anathema, the execution of any order not conforming strictly with a standard specification being literally impossible. The product has, of course, to be designed in the first instance, and the responsibility is the greater because any error is multiplied at an appalling rate, but changes are so infrequent and usually made in such very small steps that relatively little energy is normally absorbed in that direction.

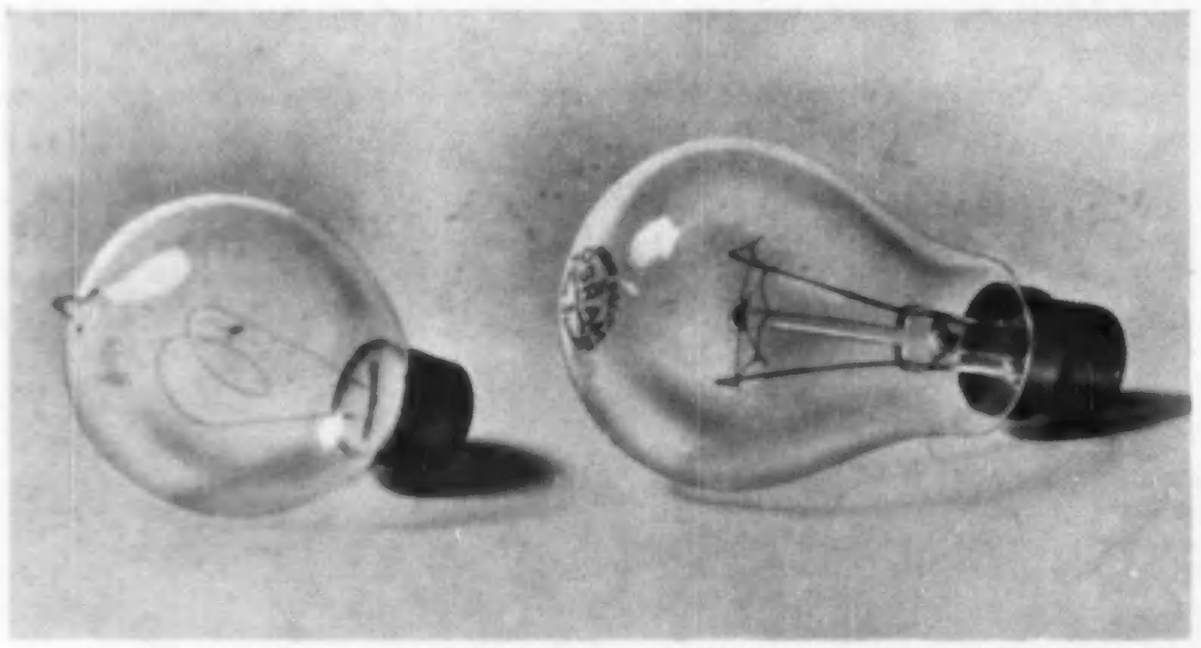


Fig. 2.—An early factory made lamp (about 1900) compared with the modern mass product (in clear bulb to show internal construction). The first is hand made and the second machine made in every detail.

When, however, we consider the means of production rather than the product, the position is exactly reversed. The general engineering shop is equipped with standard tools which can be purchased "over the counter" and which are extremely versatile; the designer can take for granted their ability to perform the tasks he sets them. The specialist mass-producer, on the other hand, has no use for general utility tools; from his point of view they are capable of many tasks but efficient in none, and his exacting standards can be satisfied only by machines designed with concentrated purpose to perform one particular operation as fast, as precisely and as economically as possible. Here, of course, the designer re-enters, and his work in an industry of this sort, though fundamentally different in kind, is at least as important as in any other. Not only must the machines themselves be designed and constantly improved to keep pace with the times, but their lay-out, the methods of feeding and removing work in progress, and every other auxiliary detail of organization need unending study.

It is, of course, the more or less complete application of these principles which is responsible for the recent gigantic increase in the productivity of certain industries, especially in the United States. The movement characterises the present century and may fairly be called the Second Industrial Revolution.

LIMITATIONS.

Since an organization of the type just described is useless except for its specialised function, and cannot vary its product even slightly without radical alteration, standardization is evidently a necessary condition before any industry can adopt it. In the case of electric lamps the process of standardization, though very incomplete, has progressed so far that roughly half the total demand has been concentrated on a range of six sizes and ratings (the ideal, if manufacturing considerations alone entered into the question, would, of course, be one only) between 15 and 100 watts, and the new factory is devoted entirely to the construction of lamps within that range. Voltage standardization lags still more; there is indeed no present hope of world agreement on distribution voltages, and even in England it is likely to be many years before lighting circuits are brought into uniformity, present practice varying from 100 to 130 and from 200 to 260 volts in different districts. A further compromise has therefore been necessary, and even though the voltages between 100 and 130, which are in relatively small demand, have been excluded from the new factory, each size of lamp must still be made for no less than seven voltages between 200 and 260. Finally, although great efforts have been made in recent years for the exclusive standardization of the diffusing "Pearl" finish, some users cling obstinately to the time-honoured glare of the unshaded bulb, so that at the present stage the nearest practicable approach to the strict ideal is—much as we may

regret it—eighty-four types of product instead of one.

To the factory designer the chief significance of such an incompleteness of standardization lies in the entailed necessity of providing more accommodation for stocks—whether of component parts or of finished goods—than would be needed if the product were utterly uniform. There must be, in effect, not one but several parallel streams of production in the factory for which supplies cannot be synchronized exactly and for which a large reserve of materials must be maintained. Worse, these streams cannot even be truly continuous; they feed the finished stock intermittently with lamps of different voltage denominations, and that stock must consequently be maintained at an adequate level to bridge over these intermissions and to meet large seasonal fluctuations in demand and fortuitous "runs" on particular ratings.

Though, in this section, the special case discussed is naturally that of the electric lamp industry, the general applicability of the implied principles is obvious. Unfortunately the benefits of standardization cannot be reaped over-night; it must be accomplished before mass production can be organized, and that organization takes time. Too often the short-sighted user, unfamiliar with the problems of manufacture, incredulous of the ultimate advantages he is promised and unable to see an immediate and adequate return for the sacrifices—frequently imaginary—which he is asked to make, presents a blank wall of resistance against all changes.

Fig. 3.—Capping lamps by hand 30 years ago.

THE HISTORY OF ELECTRIC LAMP MANUFACTURE.

The electric lamp emerged from the laboratory in the "eighties" as one of the scientific triumphs of that prolific age which impressed the contemporary lay mind as wonderful almost to the point of being miraculous. Unfortunately some of this spirit of "mumbo-jumbo" seems to have been imported with it into the industrial field. The genuine pioneers who were hoping to exploit the new invention commercially were not unnaturally bent on preserving their special secrets from the freebooters who were even then seeking a way into a business which so patently had a great future. Others, not themselves originators, who had managed by some means to obtain knowledge enough to enable them to undertake manufacture, had an even greater incentive to make a mystery of their art. Indeed, their carefully guarded recipes very often gave them their only hold on positions for which they were otherwise singularly ill-qualified. The result was that the controller of the typical early lamp factory was less a works manager than a witch-doctor who spent a good deal of his time practising hidden rites behind locked doors and who was chary of allowing the presence on his staff of men whose intelligence or education were such as might permit them to become rivals.

Conditions like these were obviously very unfavourable for rapid progress even had there been no other hindrance, but the infant industry laboured under another heavy handicap in the sheer unfamiliarity of the engineer with its principal and indispensable material—glass—though all the actual manual skill and craftsmanship needed in the service of the lampmaker were available in the existing glass industry. At the time which concerns us, however, that industry was still steeped in conservatism, and the methods of the engineer, which had already revolutionized most of the older industries, had yet made little headway against the staunch traditionalism of the glass worker, whose simple tools and personal skill were, indeed, admirably adapted to the production of the more or less ornamental objects with which he was then mainly occupied.

In retrospect it is very interesting to observe how slow and reluctant was the acceptance of the earlier mechanical improvements, and how twenty-five years had to elapse before these reactionary traditions were really completely broken down and full rein given to the development of accurate and efficient machinery. The result has naturally been that by far the greater part of the total progress has been made in the last twenty years, notwithstanding the interruption which, in Europe at any rate, was caused by the war.

For many years, then, lamps were made entirely by hand, but the original supply of skilled workers was quickly exhausted, glass working with the blow-pipe, essential in lamp assembly, being a very small off-shoot of the main glass industry. The difficulty of training newcomers was probably the first impulse towards mechanical development, while the gradual rise in wages, especially in the United States, during the thirty years before the War must have made it plain to the far-sighted that radical changes were needed to maintain, let alone reduce, production costs.

Fig. 4.—Capping and finishing machine of 1930, typical of modern high speed lamp machinery. Running at 1,000 per hour this machine, with three attendants, turns out nearly twice as much work as the room full of girls seen in fig. 3.

The first applications of machinery were very modest, amounting to little more than the provision of jigs to assist the hand-worker and reduce the skill required of him by holding parts in their proper relative positions, but more ambitious designs gradually followed and were continually replaced by improvements as the increasing scale of production gave more scope to the engineer. The process of mechanization has gained momentum enormously in the last few years through the breaking down of the barriers of secrecy by arrangements for the interchange of experience between the world's leading manufacturers, whose engineers have benefitted not only by exchange of ideas but also by the competitive spirit which has arisen.

It will not be possible here to give any detailed account of the methods and machines used in a modern lamp factory, but some idea of the scale of progress may be given by instancing such an operation as that of sealing the filament into the bulb of a lamp, which up to as late as 1900 required great skill and was performed by men by hand at a speed of about 20 per hour. By 1910, simple machines enabled semi-skilled girls to do equivalent work at about 200 per hour, while in 1930, entirely self-acting machines, running at speeds around 1,000 per hour and leaving nothing for their attendants to do but watch them, perform this operation as only a part of their duty. Such figures as these explain how it has been possible in The General Electric Co's. Works during the last twelve years to reduce the labour expended in making a lamp in a ratio greater than ten to one, and to double the earnings of the workers concurrently with a continual fall in production cost.

To sum up, it may be said that, starting from raw beginnings, a history has been compressed into forty odd years which in an older industry would probably have spread over at least a century, and that a stage has been reached only within the last few years which invites the application of the intensive methods of mass production.

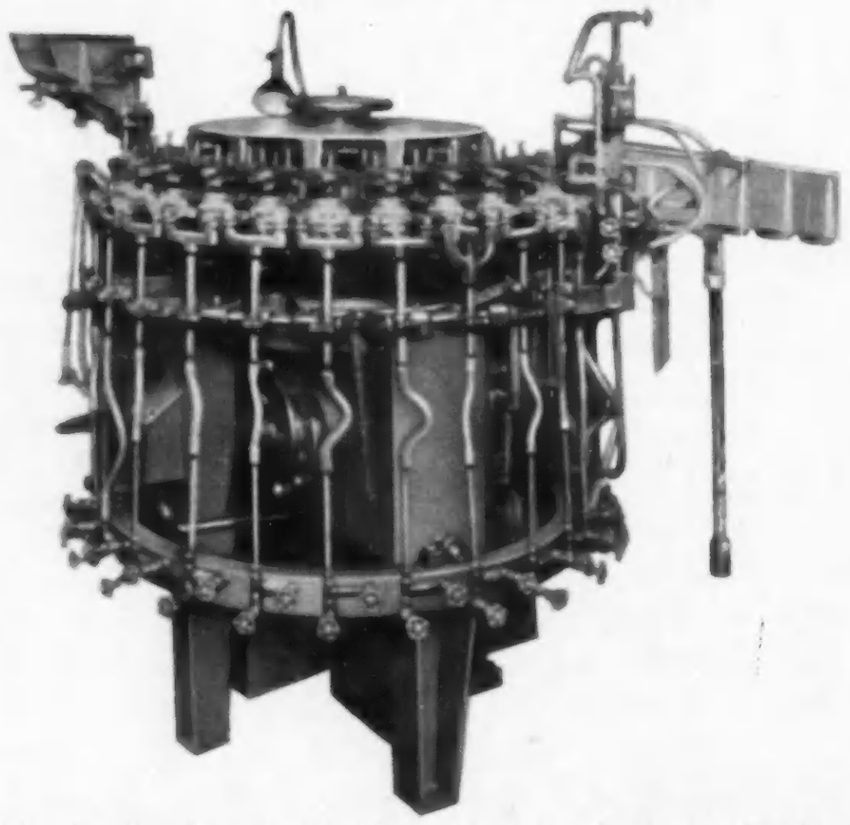


Fig. 5.—Another typical machine, which makes "feet" to carry lamp filaments at the rate of 1,200 hourly.

CO-ORDINATION WITH OTHER FACTORIES.

A modern organization for the economical production of incandescent electric lamps is constrained to produce almost everything it uses from very raw materials, mainly because its requirements are so specialised that they are not to be found among the products of general manufacturers. A brief reference to the arrangements whereby the factories owned by or associated with the G.E.C. produce the various components, will help to make plain how the new lamp factory is fed with its requirements.

The manufacture of glass has never yet been actually incorporated in a lamp works, partly because the two techniques are so different, but also because,

until the introduction of fully automatic machinery a few years ago, dependence on the skill of the glass worker made it necessary to choose a district, usually at a considerable distance from the centres of the electrical industry, where the trained men were to be found. At Wembley, however, the combination is much closer than usual, glass works having been built there some years ago to house automatic tube-drawing and bulb-blowing machinery, with the definite object of ultimately adding lamp works on an adjoining site. The realization of this plan leaves the two factories separated only by a roadway and it is believed that this is the most intimate association yet achieved in any country.

Caps are a relatively simple product; the brass shells are turned out at colossal speed by modern multiple presses of quite standard patterns, and the only unusual feature of their manufacture is the casting of the black glass buttons which hold and insulate the contact plates. The cap factory, owned jointly with other electrical companies (since no one maker could economically supply his own demand alone) is located at Chesterfield, delivery to the Wembley factory being made by rail.

The closest associations of the lamp works, however, are naturally with the parent establishment at Hammersmith from which it has just been detached and in which all non-standard lamps and a very large range of components are still made in a number of sub-divisions. The Hammersmith factories supply the filament wire which is the heart of an electric lamp, the extraordinarily pure and dry mixture of Argon and Nitrogen which is essential to the attainment of high efficiency, the complex little wire leads which provide an airtight path for the current, and innumerable other material requirements of diminishing importance. At Hammersmith also are still centred all purely managerial, technical and clerical functions except such as are employed in the daily working of the Wembley factory, which is thus left entirely free to concentrate on its special duty of high-speed production, without any outside preoccupations.

Fig. 6.—A typical modern group of operations. The workers on the left mount filaments on "feet" continuously supplied by the linked machines on the right.

THE PROCESSES OF LAMP MAKING.

It will be impossible to go at all deeply into details in this section as the machines now used are extraordinarily complex, and only so much broad description of methods can be offered as is needed to render the general account of the operation of the factory intelligible to the reader.

Before the various parts are actually united to form finished lamps, certain preliminary operations are needed. The bulbs must be washed, both to remove the unsightly "bloom" which all glass quickly acquires and to leave the inner surfaces free from deposited salts produced by atmospheric attack, the presence of which in the finished lamp is fatal to good performance. Caps must be unpacked, filled with the proper amount of cement for attachment to the lamps and set in trays ready for the operators of the capping machines. Finally—and this is an extremely sensitive and important part of the building of lamps—tungsten wire must be coiled endlessly on to larger "mandrel" wires to form the familiar helical filaments, the cores being removed, after the coils have been cut to the correct length, by chemical solution. The machines used are naturally of an automatic type and are of remarkable accuracy, some of the permissible dimensional errors in the finest filaments amounting to only a few millionths of an inch.

Assembly proper begins with the building up of glass tubes and rods into rigid "lamp-posts" to carry the filaments, their wire supports, and the conductors which lead current to them. Three machines are used. The first cuts tubes of about $\frac{7}{16}$ inch diameter into lengths of about $1\frac{1}{4}$ inch, each having a flange at one end which serves eventually to unite the entire filament carrier to the bulb. The second welds these flanged tubes to solid rods and "exhaust" tubes of smaller diameter (both supplied by the Glass Works in appropriate lengths) simultaneously fusing a pair of current conductors into each joint (see fig. 5). The third machine supplies and affixes the looped radial supports of molybdenum wire which actually hold the filaments in position.

The attachment of the filaments to the completed mounts is still usually done manually (see fig. 6), but machines are rapidly coming into use which undertake even this exceedingly delicate operation in combination with the insertion of the wire supports.

The welding together of bulbs and mounted filaments follows, and is succeeded by evacuation of the lamps, which remain in that state if they are of the "vacuum" type, or are immediately filled with a very pure and dry mixture of Argon and Nitrogen if they are rated to consume 40 watts or more, so becoming "gasfilled" lamps. In either case the bulbs are hermetically sealed at this stage by the melting off of the small "exhaust" tubes. This series of operations may be performed by two entirely separate machines—one for assembly and the other for evacuation—but latest practice is again tending to link the necessary mechanisms by automatic transfer devices, and such combinations are becoming quite usual. The lamps having been fitted by hand with cement-filled caps (threading the conducting wires through small holes in the cap contacts is one of the few operations which still successfully defies mechanization) the product is completed by one more machine which bakes and sets the cement, cuts off the excess length of the wires, solders them to the contact plates and tests the lamps by lighting before finally ejecting them (see fig. 4). It remains only to examine and re-test them for defects of constitution or appearance before they are packed for delivery to finished stock.

This very condensed account of the processes used may be rounded off by saying that the output of the various machines is usually of the order of 1,000 finished parts per hour and that whenever glass is the material undergoing work, the heat required to soften or melt it is invariably supplied by compressed air-coal gas flames, these flames also acting, with few exceptions, as the only "tools" used to cut or shape the glass parts.

[*To be continued.*]

Electric Drives for Ship's Refrigerators.

THE method of controlling the refrigerating plant on the M.V. Tuscan Star, a new Blue Star Line refrigerator cargo boat is the first system of its type. The equipment comprises three 145 h.p. compressors, a booster set, two cooling water pumps and brine pumps.

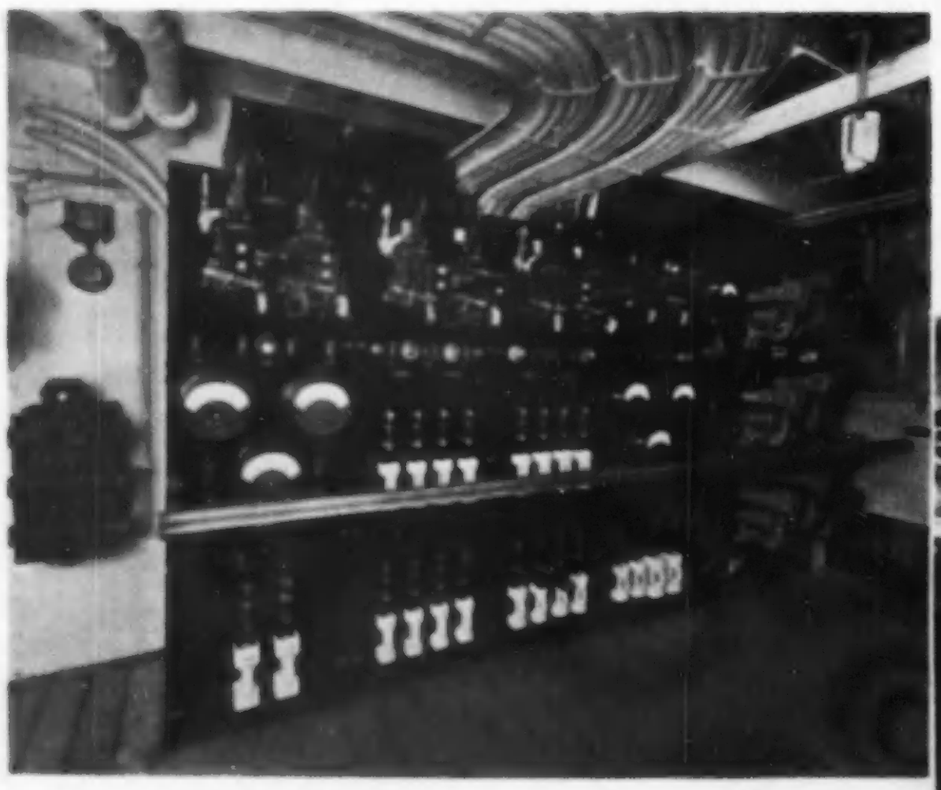


Fig. 1.—Control board, showing booster starter and change-over contactors on extreme right.

The introduction of a booster is of interest for the reason that the full power of the compressors is seldom required except when freezing down cargo, and during a voyage, only one machine, running dead slow, is required to maintain a suitably low temperature. The speed range thus demanded is too wide for shunt regulation and a series resistance is inserted in the armature circuit of each motor. On a long voyage, however, the energy loss would be considerable, and to avoid this a "negative booster" is installed together with hand-operated selection switches to allow of its introduction into any one compressor circuit. This arrangement not only gives a saving of energy but also a very much finer speed adjustment by varying the booster field.

In order to avoid shutting down a compressor while the booster is inserted or removed from its circuit, an automatic equipment is installed which makes an uninterrupted change-over by the simple operation of a push button.

Fig. 2.—Three 145 h.p. electric motor driven compressors.

The Design of High Power Heavy Oil Engines

(Continued)

By G. A. MELLOR, A.M.I.Mech.E.
Oil Engine Dept., Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

ALTHOUGH in the piston now used in the Fraser & Chalmers' oil engine (described in the *G.E.C. Journal*, Vol. 1, No. 3, page 127), the disadvantages mentioned have been controlled to a certain extent by good design and careful treatment of the metal prior to commercial service, nevertheless, as with all other conventional designs, only a partial success has been obtained.

NEW DESIGN OF PISTON.

In another design which is now being tried out, an attempt has been made to overcome these disadvantages and, incidentally, to reduce the reciprocating weight.

This new piston is illustrated in fig. 13. Due to its tubular shape and symmetrical design, perfect concentricity is maintained. The following are its chief advantages :

(*a*) The spherical gudgeon not only gives a larger bearing surface than can be obtained by a cross-head or gudgeon pin, but also takes the weight or load from the middle of the piston right under the blow of combustion and not from the sides as in conventional designs.

(*b*) There can be no longitudinal tilting of the piston due to crankshaft or connecting rod reactions.

(*c*) Due to the greater surface area of the spherical gudgeon, the bearing pressure is reduced to the same as that on the bottom end bearing.

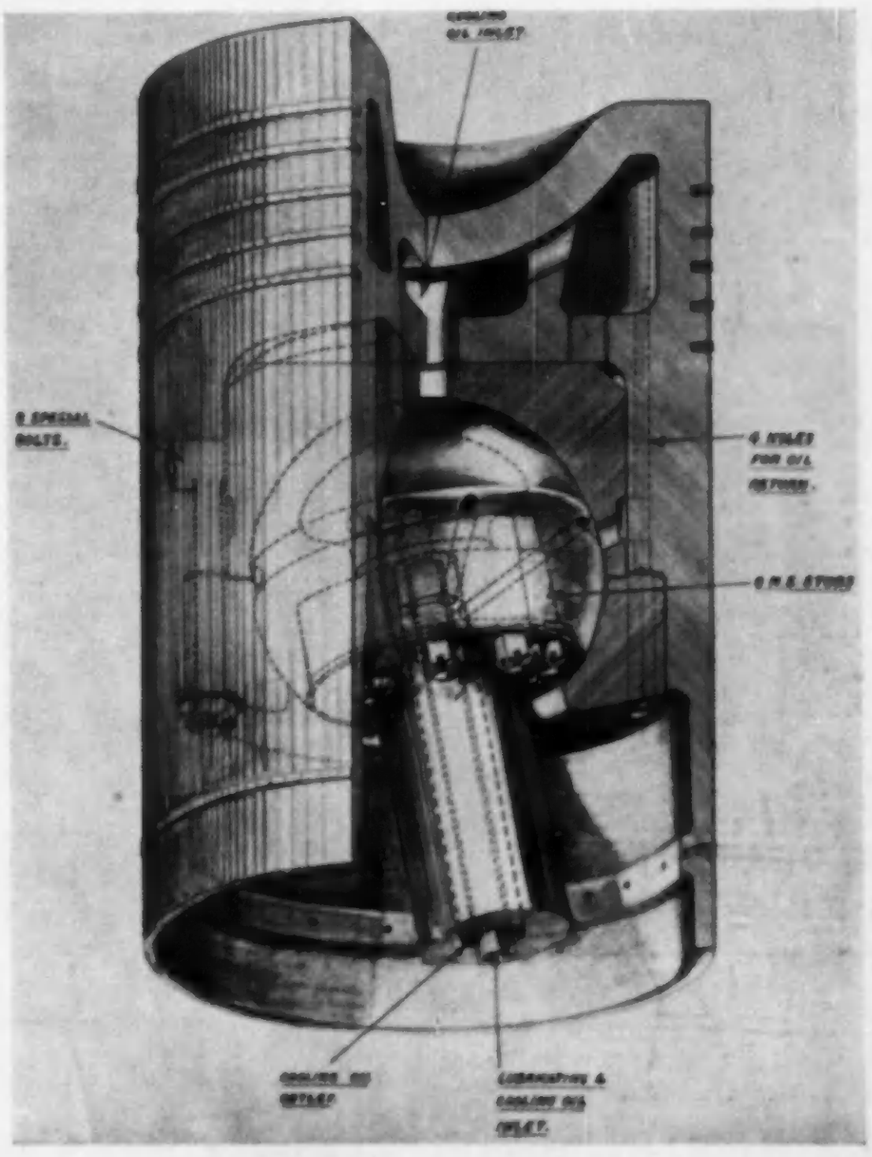


Fig. 13.—New form of piston with spherical gudgeon.

(*d*) The spherical bearing can be adjusted without withdrawing the piston by means of shims fitted between the two halves of the bearing.

(*e*) Cooling oil passes up the rod through the sphere direct to the centre of the piston head, without traversing tortuous passages as in the older types. It leaves at the highest point of the piston head through numerous holes, so maintaining a definite and complete circulation. Owing to the absence of pockets, etc., no air-lock in the oil system can occur.

(*f*) The transfer of the cooling oil to the outside of the engine is carried out in a simple and straightforward manner.

(*g*) The connecting rod is simple to forge and manufacture.

(*h*) The piston moves circumferentially during its reciprocation, thereby assisting lubrication and ensuring even wear throughout.

(*j*) Bearings are of aluminium. Preliminary tests have given every indication that these bearings will continue to operate successfully.

(*k*) The reciprocating weight has been reduced from 1,350 to 1,090 lbs.

The performance of these pistons fitted in two engines in commercial operation is being watched with interest, but insufficient time has elapsed for a final judgment to be made.

GOVERNORS.

On several of the early engines the "Hartung" type of governor was fitted, but this was subsequently replaced by a new type of governor which enabled a standardized size to be fitted to all engines.

The drive of the new governor is transmitted by a rectangular shaft which eliminates the use of cotters or keys and keeps the driving surfaces as large as possible with a small surface loading. The governor with its arms, brackets and weights is a floating unit; as the weights rotate outwards, ball-ended levers press upon a fixed hardened steel plane,

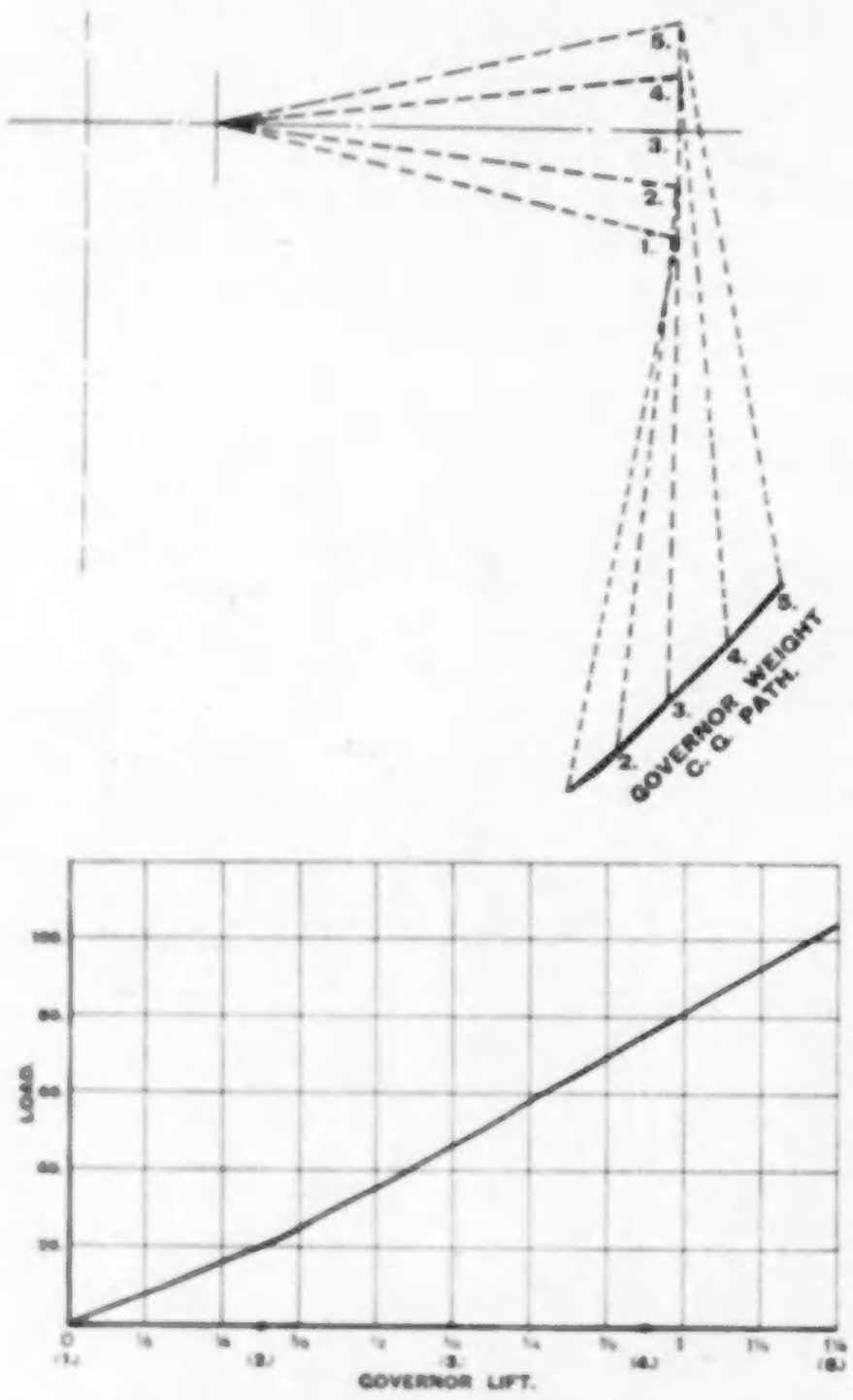


Fig. 14.—Curves of governor weight paths, and centrifugal force plotted against a spring load.

thus causing the whole of the governor to move upwards against the stationary governor spring, all the thrust forces being taken by a ball bearing. The complete governor works under an oil spray and runs at about 500 r.p.m. Friction has been reduced to a minimum by the use of ball bearings fitted at all fulcrum points and, in the case of the rectangular drive, by hardening and grinding all rubbing and driving surfaces.

Where the engine is driving an alternator, a small electric motor is usually fitted for varying the speed of the engine. This motor is controlled from the switchboard.

The curves of governor weight paths, and centrifugal force, plotted against a spring load for the total range of the governor, are shown in fig. 14. It will be seen that the curve has the correct characteristics for sensitiveness without producing hunting.

VIBRATION TROUBLES AND THEIR REMEDIES.

In the design of a modern heavy oil engine, with its moderately high revolutions, high piston speed and high m.i.p., every care has to be taken to provide sufficiently rigid framing and supports. With the particular engines under review it was early appreciated that, to obtain this rigidity, the crank case and bedplate must be sufficiently heavy to prevent the transmission of inertia and centrifugal loads between adjacent cylinders. Light scantlings, for instance, may produce serious vibration troubles even although the engine itself may be well balanced. Thus, to ensure adequate strength, the bedplate is "box-sectioned" under each bearing, while the bearing caps appear at first sight to be more massive than is really necessary. Yet these, together with the large bearing studs, must possess great strength if vibration is to be avoided.

THREE CYLINDER CRANKSHAFT.

The primary and secondary forces produced by the rotating and reciprocating masses of a 3-cylinder crankshaft are balanced with three cranks at 120°, but the primary and secondary couples remain unbalanced and form a pure couple which has a tendency to rock the engine about its centre.

The unbalanced couple due to the revolving masses may be eliminated by balance weights attached to the crank webs, the centrifugal effect being made equal to that of the revolving masses at

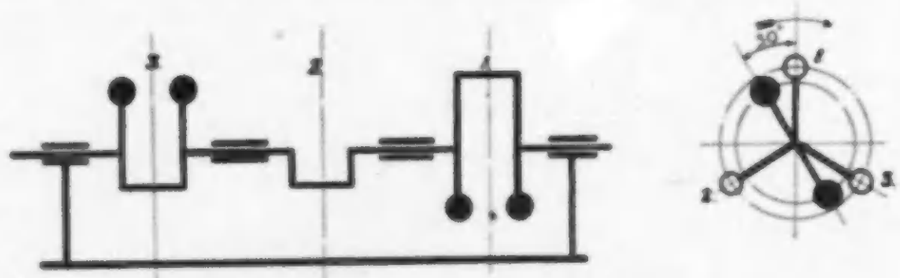


Fig. 15.—Method of balancing a three-throw crankshaft.

each crank. The unbalanced couple, due to the reciprocating masses, however, still remains. An endeavour has been made to reduce this unbalanced couple by a special arrangement of weights.

Thus it will be seen from fig. 15 that in the three-throw crankshaft, instead of fitting weights to each crank, two balance weights are substituted on the extreme cranks only. Such a system, while throwing more strain on the structure than that of independent crank balancing, is just as effective when the necessary rigidity is provided in the

crankcase and bedplate. With this system, balance weights have no effect on force balance.

A 3-cylinder engine has been tested without balance weights and the results indicate that the unbalanced couple is too severe for smooth running and renders the engine unsuitable for generator drive without a rigid combination bedplate.

FOUR-CYLINDER CRANKSHAFTS.

The first Fraser & Chalmers' oil engine had a crankshaft of four cranks. It was soon appreciated that secondary vertical forces, produced by the acceleration of the reciprocating masses and by the obliquity of the connecting rod, were out of balance. They had a value of + 13 tons maximum and a minimum of − 13 tons, acting 600 times a minute in a vertical direction. This was sufficient to shake the foundation.

It is of interest to record that when tested at the works, this engine exhibited no exterior disturbance from these unbalanced forces. This was chiefly due to the solid chalk on which the concrete block was built. As soon as the engine was removed to its site on a clay subsoil, serious vibration was felt in the vicinity of the power station. Eventually the trouble was eliminated by fitting secondary balance weights as shown in figs. 16 and 17.

Owing to the moderately high speed of this engine it was possible to accommodate two revolving secondary weights at each end of the bedplate, equidistant from the centre line of the engine masses and neatly housed under the end bridges of the crankcase. Each set of balancing gear rotated in force lubricated roller bearings. Laminated stepped spur gears were first fitted, but these were replaced later by Maag spur gears which have run satisfactorily and noiselessly ever since they were fitted.

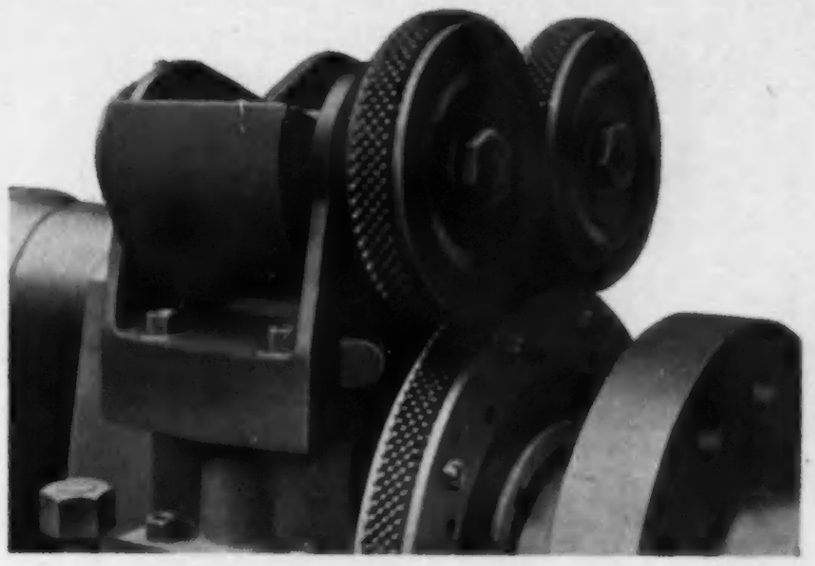
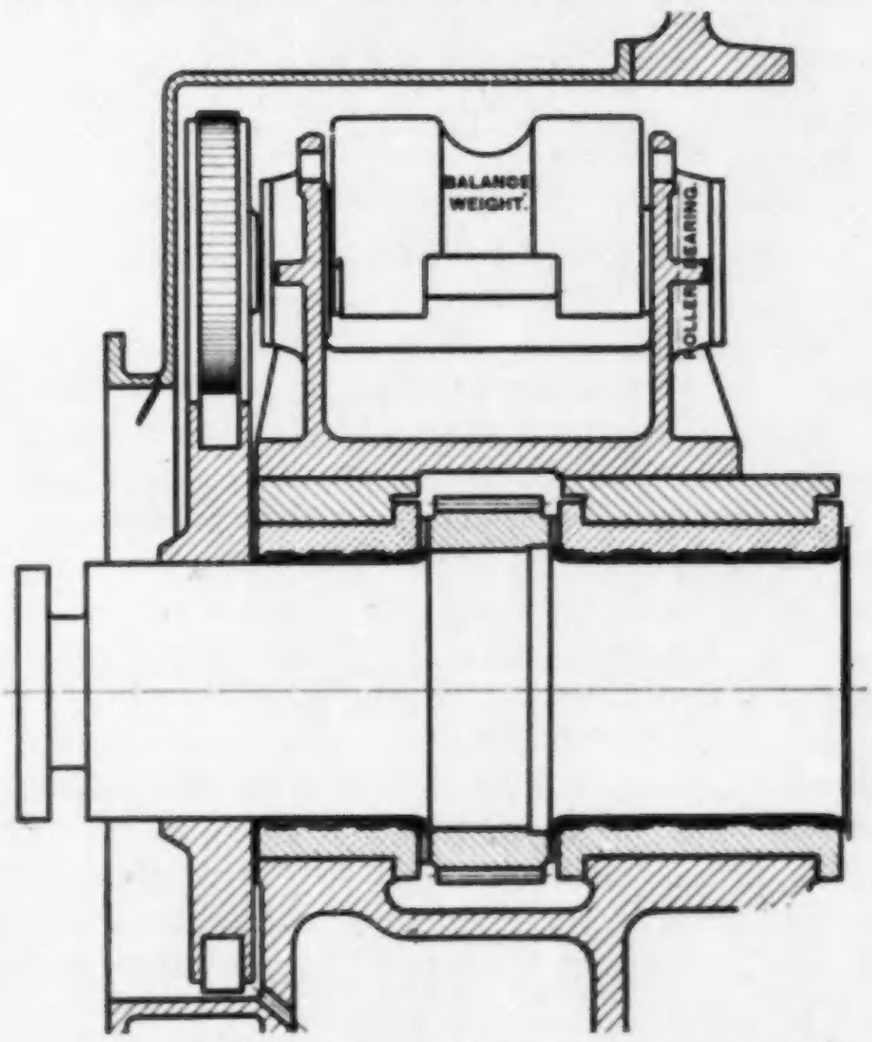


Fig. 16.—Method of gearing secondary balance weights to four-throw crankshaft.



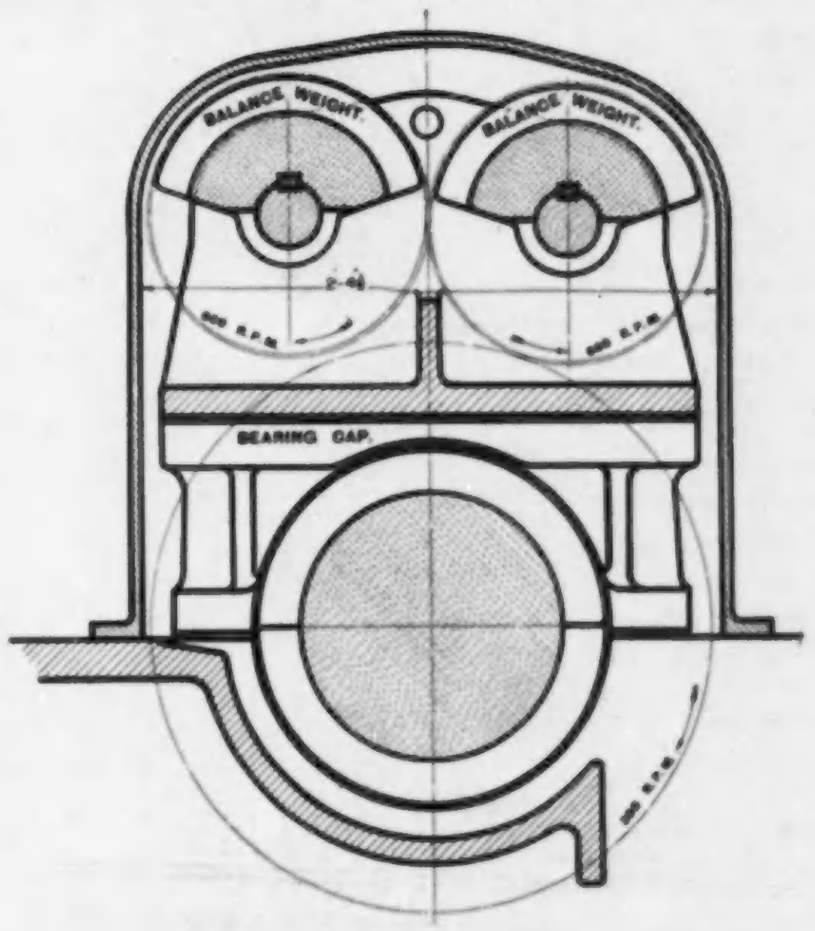


Fig. 17.—Sectional view showing secondary balance weights fitted on a four-throw crankshaft.

This type of balancing gear, running as it does at 600 r.p.m., must be housed very rigidly, otherwise springing will occur in the casting. The shafts carrying the forged steel weights, which are filled with lead, are 3 inches in diameter.

The curves (fig. 18) show the secondary forces for the four cylinder engine and the resultant due to fitting balancing gear.

It may be of interest to review a few experiences in connection with vibration on four-cylinder engines. Generally speaking, water-borne clay subsoils have been found unsuitable for this type of engine unless erected on an extremely heavy concrete

block with resilient cork inserted beneath the block.

In the case of an early engine supplied without balancing gear, the secondary forces were so large that the disturbance could be felt within a half-mile radius of the engine. When the balancing gear was fitted, these vibrations were completely eliminated. One such engine is in operation next to an important block of offices in London without causing annoyance.

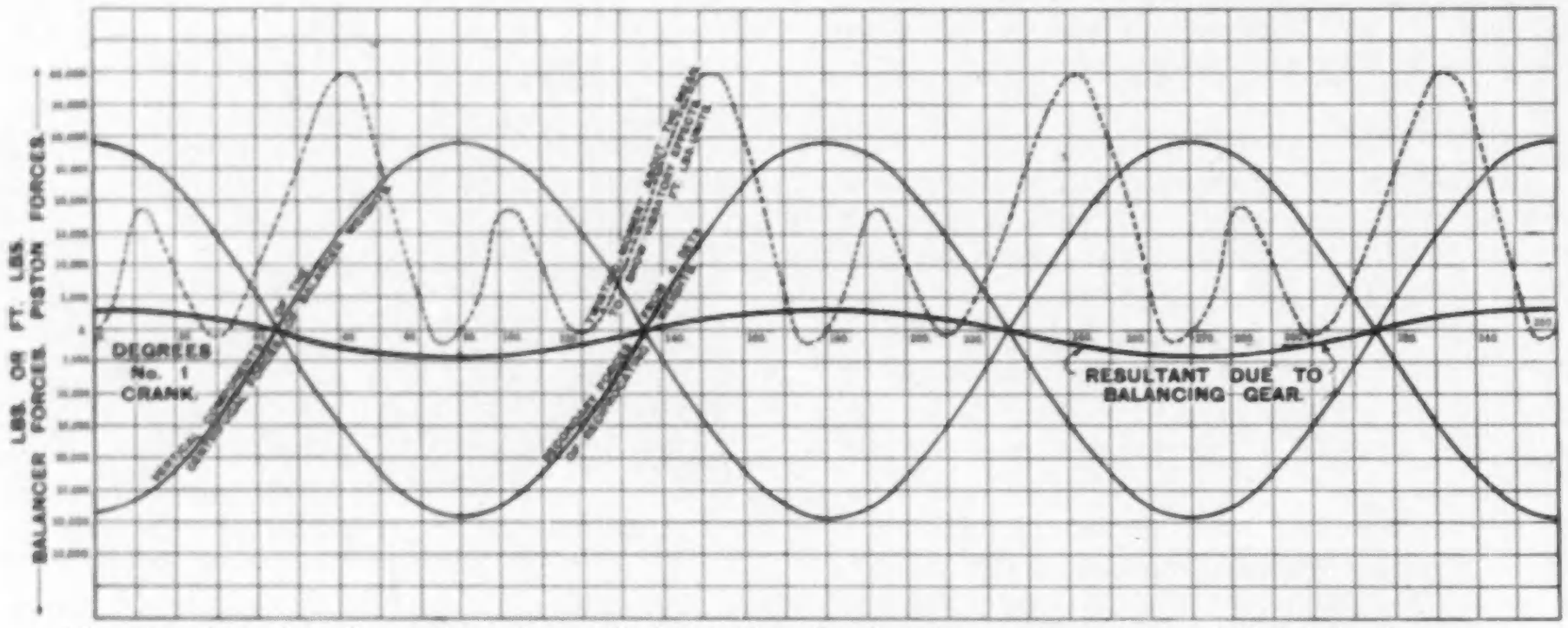
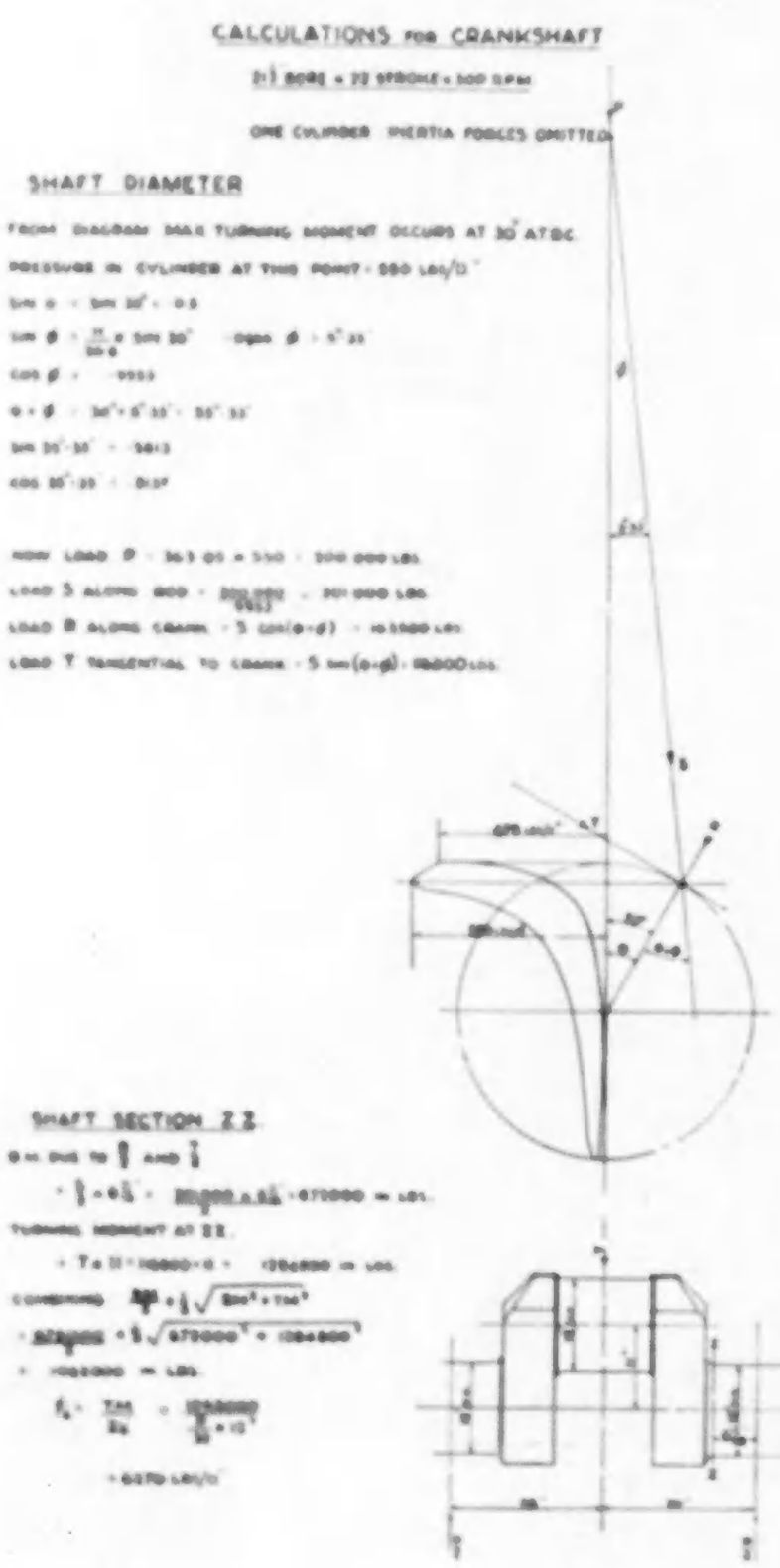


Fig. 18.—Secondary forces for a four cylinder engine showing the resultant due to fitting balancing gear.



In another case, where a four-cylinder engine was sent abroad, the balancing gear was fitted prior to shipment. The ground structure on which the engine was mounted consisted of solid rock and during an overhaul the balancing gear was removed and the engine purposely assembled again without it. It was then found that the surrounding locality was just as free from vibration without the balancing gear as with it. It was evident that the rock in which the foundation block was inserted possessed a mass of sufficient magnitude to reduce the amplitude of the transmitted vibrations to a negligible amount.

Four-cylinder engines of large power, *i.e.*, between 500 and 1,000 h.p., have been considered too large to give satisfactory running because of the magnitude of the unbalanced forces. It has been definitely proved, however, that even these unbalanced forces can be eliminated by the fitting of carefully designed balance gear.

It should also be mentioned that, had cast iron pistons been used in these engines, the solution of these vibration problems would have been more difficult to accomplish. As it is, the balancing gear now adopted is not only reliable, but in all cases has proved to be most satisfactory.

TORSIONAL VIBRATIONS.

A frequent and very elusive trouble which every manufacturer of high power moderate speed engines encounters, is concerned with torsional vibration. An example of this was afforded by an early engine, the intermediate shaft of which fractured at a point between the flywheel and the generator it was driving. After careful investigation

it was found that the natural frequency of the two main shaft masses was such as to cause a critical vibration at about 20 r.p.m. from the running speed. A further series of tests carried out by the G.E.C. Research Laboratories at Wembley, clearly showed from the data available that the fracture was caused by torsional fatigue.

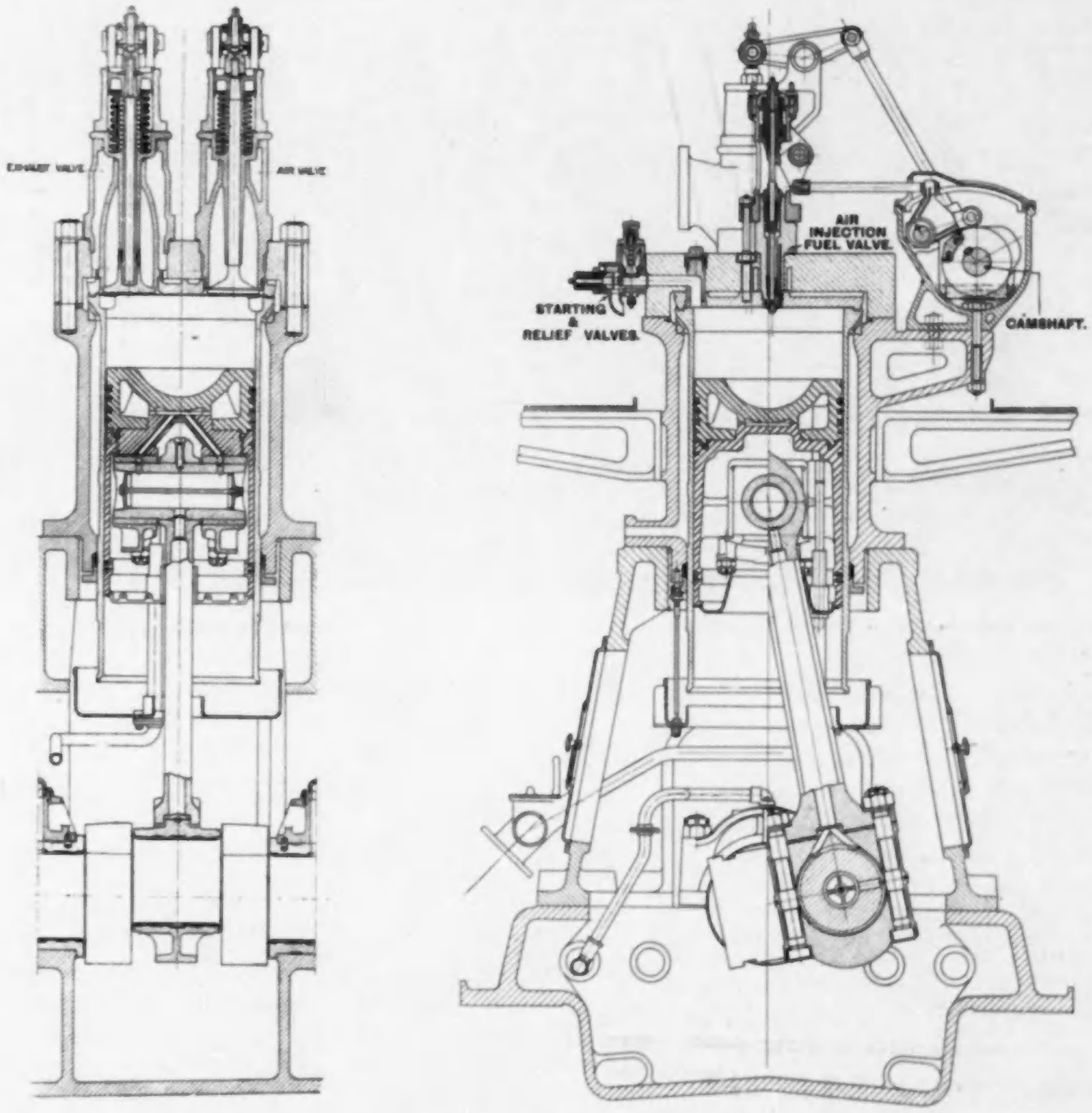


Fig. 19.—Sectional views of a Fraser & Chalmers' heavy oil engine.

It will be appreciated that it is very difficult to estimate the stiffness of a complicated member like an armature hub with all its fastenings. A small difference in shaft diameter will, due to some incalculable effect, mean either success or failure.

In this particular instance, a new intermediate shaft was fitted having an increased diameter of 1⅛ inches, which was calculated to raise the critical speed out of the danger zone. Careful tests were then carried out by means of a Gieger Torsiometer which confirmed the calculations.

The use of such an instrument as the Gieger Torsiometer is invaluable in tests of this kind for it not only discloses the natural frequency of the system and its various critical speeds but it also indicates the relative magnitudes of the stresses in the shaft at these critical speeds. It is obvious that had such an instrument been available at the time of manufacture of this engine, the dangerous stresses would have been discovered and corrected immediately.

This example illustrates how an engine may be running in commercial service for quite a long time dangerously near a critical speed without showing any abnormal symptoms before trouble occurs. It also serves to show the importance of investigating the torsional characteristics in every design of engine shaft.

Torsional oscillations are sometimes minimised by fitting dampers at the free end of the crankshaft. This method at its best is more a palliative than a remedy and is not to be recommended unless the whole rotating mass system has to run at varying speeds.

LUBRICATION.

One oil is used for the lubrication of all parts including liners and pistons, all bearings and crankshaft running gear and air compressor. Difficulties have been encountered in the correct lubrication of liner and piston with certain oils, which produced a heavy carbon deposit resulting in a heavy knock on the induction stroke when the engine was started up cold. This noise disappeared as soon as the lubrication feeds began to function and had moistened the whole of the piston surfaces with oil. This trouble is avoided by using an oil which impregnates the aluminium surface of the piston and, at the same time, retains its surface tension on the steel liner without leaving dry patches when the engine cools down after running on full load. The characteristics of the oil now used are given in the following table.

Viscosity Grade.	Nominal Viscosity (Redwood) at 140° F.	Specific Gravity.	Closed flash point °F. min.	Viscosity seconds 140° F.	Cold Test to be below.	Hard Asphalte.
Heavy.	190	.892	400	200	30°F.	Nil.

AIR INJECTION COMPRESSOR.

Compressed air injection is essential with this type of engine. Mechanical injection for so large a combustion space and for the high m.i.p. required, does not give the results obtained with compressed air. If the maximum m.i.p. never exceeded 95 lbs., a clean exhaust might be expected, but since 120 lbs. m.i.p. is a common full load figure, it is better to expend 10 lbs. of this in driving the compressor and thereby obtain an ultimate increase in the h.p. delivered at the crankshaft. It can be shown that the net increase of power obtained by adopting air injection is about 15 per cent. more than that obtained by the use of any known system of mechanical injection.

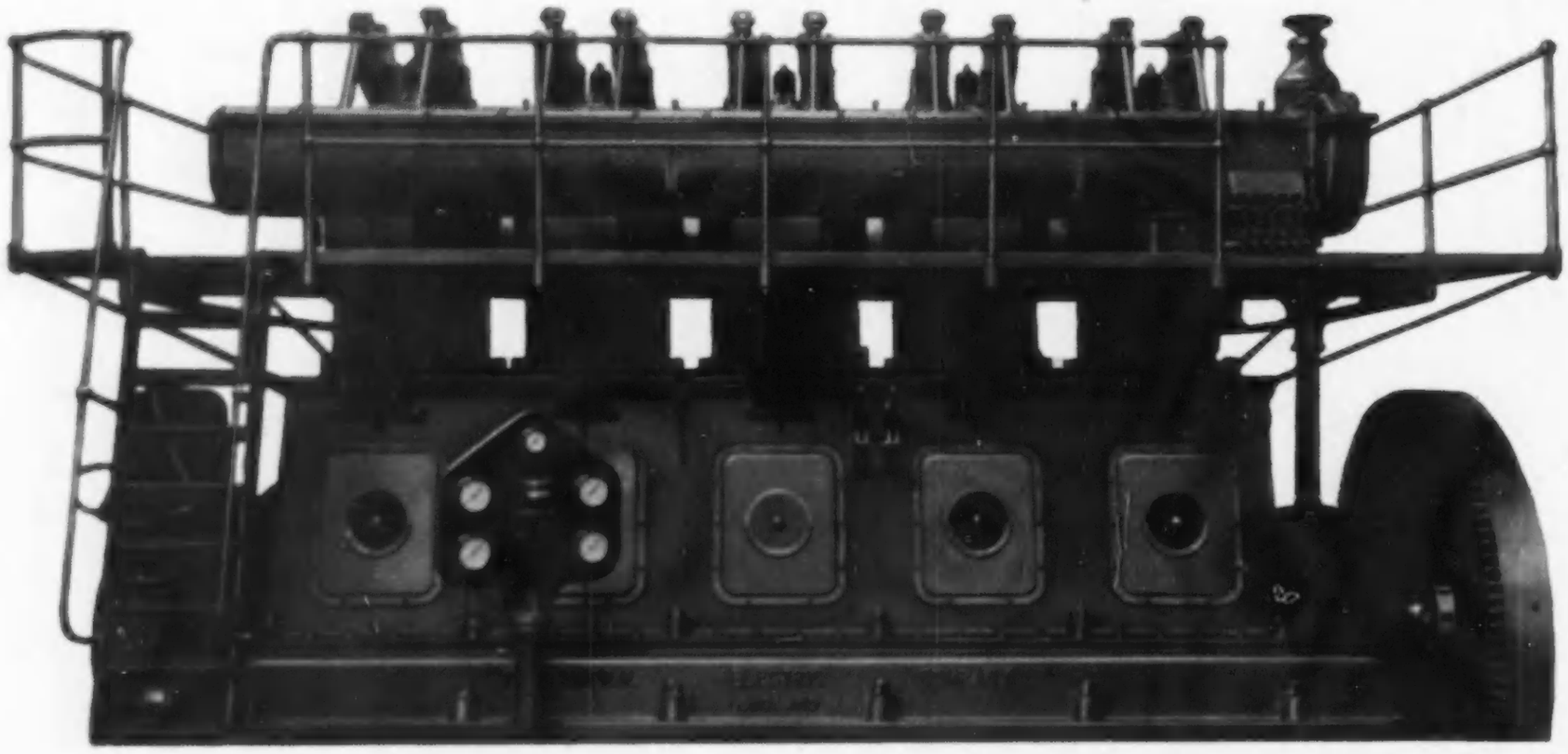


Fig. 20.—A typical 5-cylinder Fraser & Chalmers' heavy oil engine.

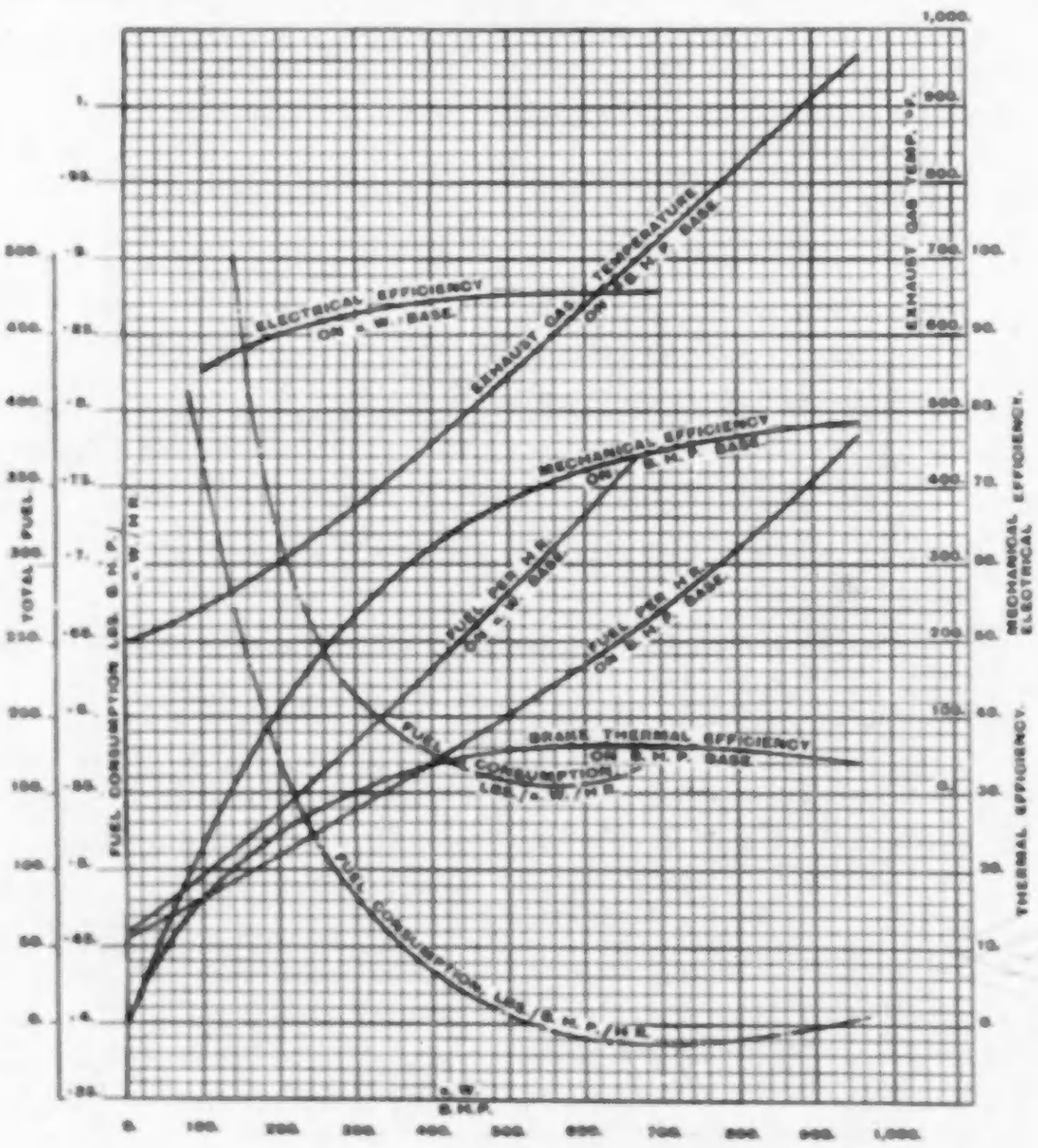

ELECTRICAL EFFICIENCY ON K.W. BASE
EXHAUST GAS TEMPERATURE ON B.H.P. BASE
MECHANICAL EFFICIENCY ON B.H.P. BASE
FUEL PER H.P. HR. ON K.W. BASE
FUEL PER H.P. HR. ON B.H.P. BASE
BRAKE THERMAL EFFICIENCY ON B.H.P. BASE
FUEL CONSUMPTION LBS/B.H.P./HR.
TOTAL FUEL CONSUMPTION LBS. B.H.P./K.W./HR.
EXHAUST GAS TEMP. °F.
MECHANICAL EFFICIENCY. ELECTRICAL EFFICIENCY.
THERMAL EFFICIENCY.
K.W.
B.H.P.

Fig. 21.—Test curves for an 800 h.p. heavy oil engine driving a 560 kW generator.

Installing Oil-Filled Cable.

By R. E. HORLEY, A.M.I.E.E., A.M.A.I.E.E.

Works Manager, Eastleigh Factory, Pirelli-General Cable Works, Ltd.

In this, the last of a series of three articles dealing with oil-filled cables, the author outlines the various processes involved in the actual laying of this class of cable, and describes the means by which perfect impregnating is maintained during the jointing processes.

WHILE oil-filled cable may be installed by any one of the three well-known methods—laying direct in the ground, laying in concrete troughing or pulling into ducts—the first method is commonly used in England as it is generally assumed to be cheapest in first cost. This assumption, however, is not always correct, for if the expense of re-opening the ground is to be avoided, sufficient cable has to be laid in the first instance to meet requirements for many years to come. On the other hand, with a duct line having spare runs it is only necessary to install sufficient cable to meet existing demands, additional cable being pulled into the spare runs when required at comparatively little extra expense.

A further very important advantage of the duct line is the ease with which inspection of the cable can be accomplished. This applies equally to oil-filled cables and to those of other types. The advantages of ease of inspection are very considerable, especially where it is necessary to provide for the maintenance of cables carrying very large blocks of power at high voltages. This point of view is apt to be overlooked by engineers who are more familiar with the direct laid system.

OIL FEEDING ARRANGEMENTS.

In every oil-filled cable installation the lengths of cable are joined together to form a number of sections, each of which is electrically connected to, but hydrostatically separate from, adjacent sections. It is essential that during the jointing processes, not only shall the oil in the cable be maintained in a gas-free condition, but the cable itself must retain

G3559

Fig. 1.—Laying 132 kV oil-filled cable in London.

the same state of perfect impregnation which it possessed when leaving the factory.

Before the lengths of cable are actually laid, it is necessary to make arrangements for feeding them with oil while they are waiting to be jointed, and during the jointing processes. Feeding tanks or pressure tanks are accordingly installed at various points along the profile of the route. These tanks can be placed in their permanent position or, if necessary, a temporary arrangement can be adopted. Laying can then be started from any convenient feeding point.

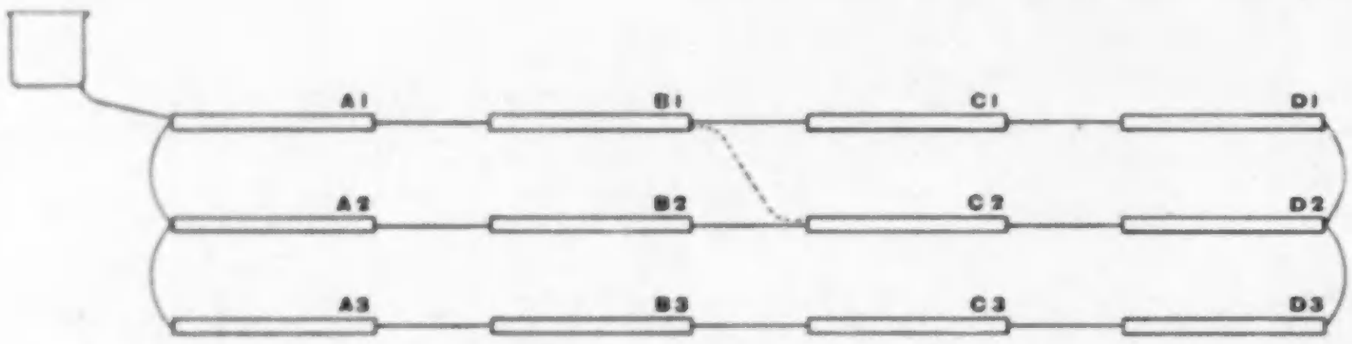


Fig. 2.—Illustrating method of oil feeding during jointing processes.

The first length of cable is pulled towards this feeding point and, as soon as its end is connected to the feeding tank, the small tank mounted in the cable drum (which until now has been feeding the cable) is disconnected and the drum with its tank returned to the factory for further use.

The next length of cable on the route is pulled towards the free end of the first length, and the two ends are connected by means of an armoured pipe so that the oil in both lengths is maintained under pressure from the feeding point. The second drum tank is then disconnected. In this way any number of lengths in a section can be connected together and left in the ground until it is convenient to begin jointing.

It is important to note that all joints between the lengths of cable, or between the oil pipes containing oil, are made with the oil at a pressure slightly above that of the atmosphere. This ensures that oil will flow out at these points while the joint or connection is being made, the outflow preventing the ingress of air and moisture.

It will be seen from fig. 2 that it is possible to remove two of the three connecting pipes, say A1 and A2, at any joint hole and still comply with the conditions of oil flow from both sides of the joints. It is also possible by means of jumper pipes, such as that shown dotted at B, to carry out jointing at other points at the same time as at A.

MAKING THE JOINT.

To prepare the cable for jointing, the two ends are lined up and the outer lead sheaths and armouring removed for a short distance from each end. The cable is then cut to the required length and the centre channel is fitted at each end with short steel plugs, provided with oil passages which are temporarily stopped by means of fibre stoppers. Sufficient lead sheath only is removed from the two ends to be jointed for the insulation to be cut away and a copper connecting ferrule to be fitted over the exposed ends of the conductors, after removing the fibre stoppers.

The continual restricted flow of oil renders it impracticable to solder the ferrule to the conductors. Use is therefore made of a small hydraulic press (fig. 3) which squeezes the ferrule solidly on to the conductor at a pressure of about 30 tons per sq. in., the conductor being supported against this pressure by the steel plugs previously introduced into the channels. The resulting joint which is both mechanically strong and electrically sound, is shown in fig. 4.

The next steps are to remove more of the lead sheath for a distance equal to the length of the joint, and to tape the insulation thus exposed with silk and varnish tape. This restricts the flow of the oil and enables the insulating of the ferrule to be started.

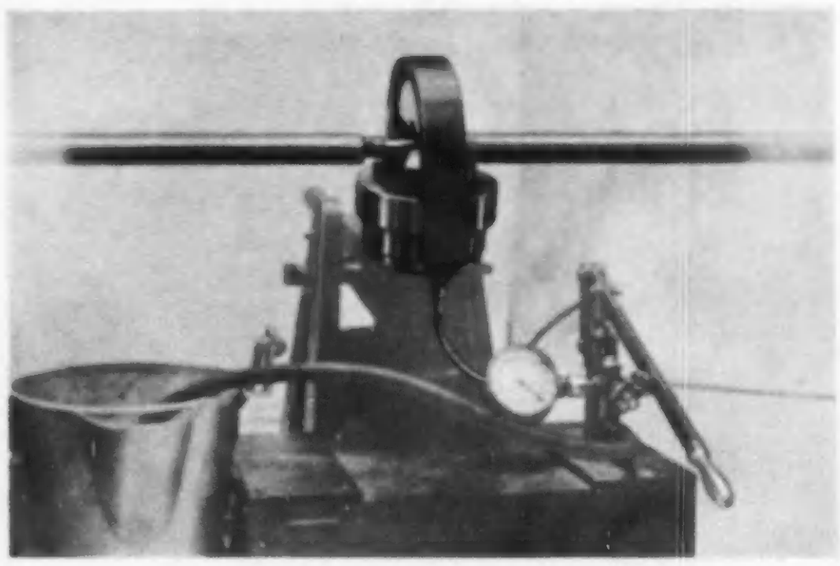


Fig. 3.—Portable hydraulic press used for squeezing ferrule on to conductor at a pressure of 30 tons per square inch.

The ferrule is insulated by means of an impregnated paper tube (fig. 5) which is taped to a diameter equal to that over the insulation of the cable. This provides a straight landing from end to end of the joint (fig. 6) for the reception of the main joint insulation.

A taping machine (fig. 7) is clamped over the joint and revolves on two bushes fitted on the lead sheaths of the cable at each end of the joint. This machine carries a large number of rolls of impregnated paper (fig. 8) which is wound on to the joint by revolving the machine until the joint is insulated to the required thickness. More insulation is applied to the middle of the joint than to the ends, thus forming the usual cigar shape (fig. 9). Less cutting away is therefore required to fit the metal trumpet electrostatic screens which cover the joint from end to end and connect the lead sheaths together (fig. 10).

The external copper sleeve, shown in fig. 11, is placed over the joint and plumbed to the lead sheaths of the cable. When the cable is laid direct in the ground, further protection for the joint is provided by means of a concrete box.

Fig. 4.—Ferrule in position on joint.

Fig. 5.—Ferrule insulated with paper tube.

Fig. 6.—Joint taped to present straight landing from end to end.

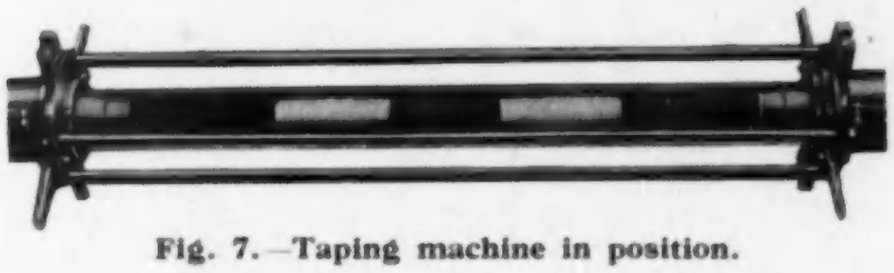


Fig. 7.—Taping machine in position.

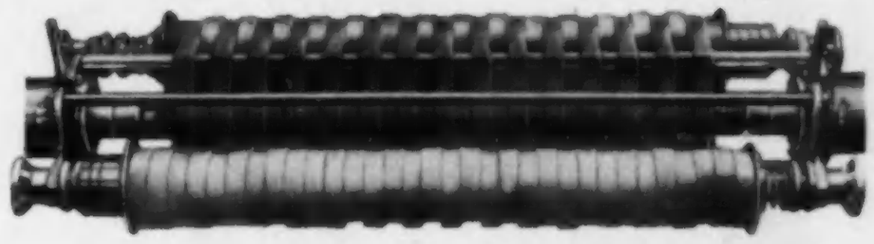


Fig. 8.—Taping machine winding impregnated paper on joint.

Fig. 9.—Resultant shape of insulation on joint.

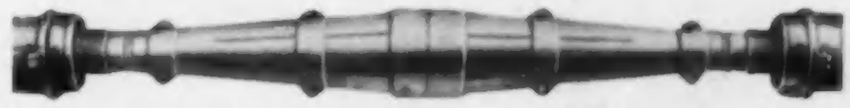


Fig. 10.—Joint fitted with electrostatic screens.

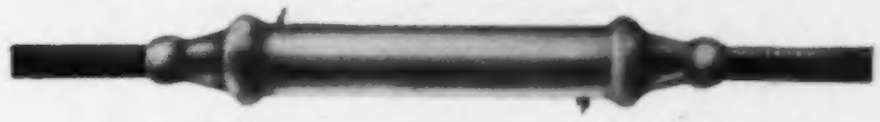


Fig. 11.—External copper sleeve fitted over joint.

IMPREGNATING THE JOINT.

In order to impregnate the joint it is first heated by means of an electric heater, vacuum being maintained in the sleeve, and dried, degasified oil admitted from a portable pressure tank. An impregnation test is then made and the joint closed.

STOP JOINTS.

As explained in the previous article, the insulation of the stop joints is carried out in the factory under ideal conditions, and the work to be executed on site consists of the fitting of spring contact plugs to the ends of the cable in the jointing bay and the fitting of metal bells at the ends of the lead sheath to modify the stress at these points. The procedure is as follows :—

The ends of the cable where the stop joints are to be fitted, are first stripped for a suitable distance of both lead sheath and armouring, and the exposed insulation taped with silk cambric. The centre channel is fitted with steel tubes the centre passages of which are stopped with fibre plugs to restrict the outflow of oil. The conductors of the cable are exposed and spring contact plugs are pressed on by the portable press in the manner just described. During the operation of the system, oil has generally to be fed into the cable at the stop joints ; it is therefore necessary to leave an oil passage in the plug connectors. These oil passages are temporarily closed during installation by means of a small valve which is kept in position by the pressure of oil inside the hollow core.

The exposed cable insulation is reinforced near the lead sheath by means of impregnated paper tubes wound on and tightened in position. The ends of the tube are trimmed with sharp knives to fit the stress bells. When these bells are fitted and connected to the lead sheath, the end is ready for insertion into the stop joint casing for which purpose a certain amount of slack has to be allowed in the cable near the joint bay. The cable is pushed home until the spring plugs make contact with the socket end-caps of the insulators of the stop joint. The process of jointing is completed by plumbing the cable lead sheath on to the ends of the stop joint case.

The insulators into which the cable ends have been fitted are next filled with oil. This is accomplished by means of two conical connectors fitted into the case, one on top and one underneath. Vacuum is maintained in the upper connector and oil admitted through the lower.

As soon as these spaces are completely filled with oil the pressure on the oil is increased until it exceeds that of the oil inside the cable itself, thus pushing out the small valves in the spring plugs and thereby establishing communication between the external oil supply and the interior of the cable.

It should be appreciated that the small valves are purely a temporary measure and only function during the making of the joint. They prevent oil flowing from the centre of the cable into the inside of the insulators and so destroying the vacuum during the oil-filling process. The same problem presents itself in the case of the terminal insulators when these are being impregnated, but in this instance the top cap of the insulator is easily accessible, the valve consisting of a steel rod which can be removed by hand.

The final operation on the stop joint is to connect the central chamber, which has been filled with oil in the factory, to one side of the cable so that the oil in the centre of the joint will always be under pressure. This connection is made by an external copper pipe.

MAINTENANCE OF OIL FEEDING POINTS.

For the impregnating processes necessary to complete the installation of straight joints, stop joints and sealing ends, a supply of dried, degasified oil is necessary.

An oil-filling station has to be set up at some convenient point in the field to which drums of oil are despatched from the factory. Oil from these drums is pumped through a field type degasifier into the portable tanks, frequent tests being made to check the condition of the oil.

This is then sent in portable pressure tanks or feeding tanks to the point at which it is required. Pressure tanks are used for the stop joints (where pressure is required to operate the plug valves) and for the sealing ends which are generally fixed at a height above ground level. The greater capacity of the feeding tanks make them useful for joint impregnation.

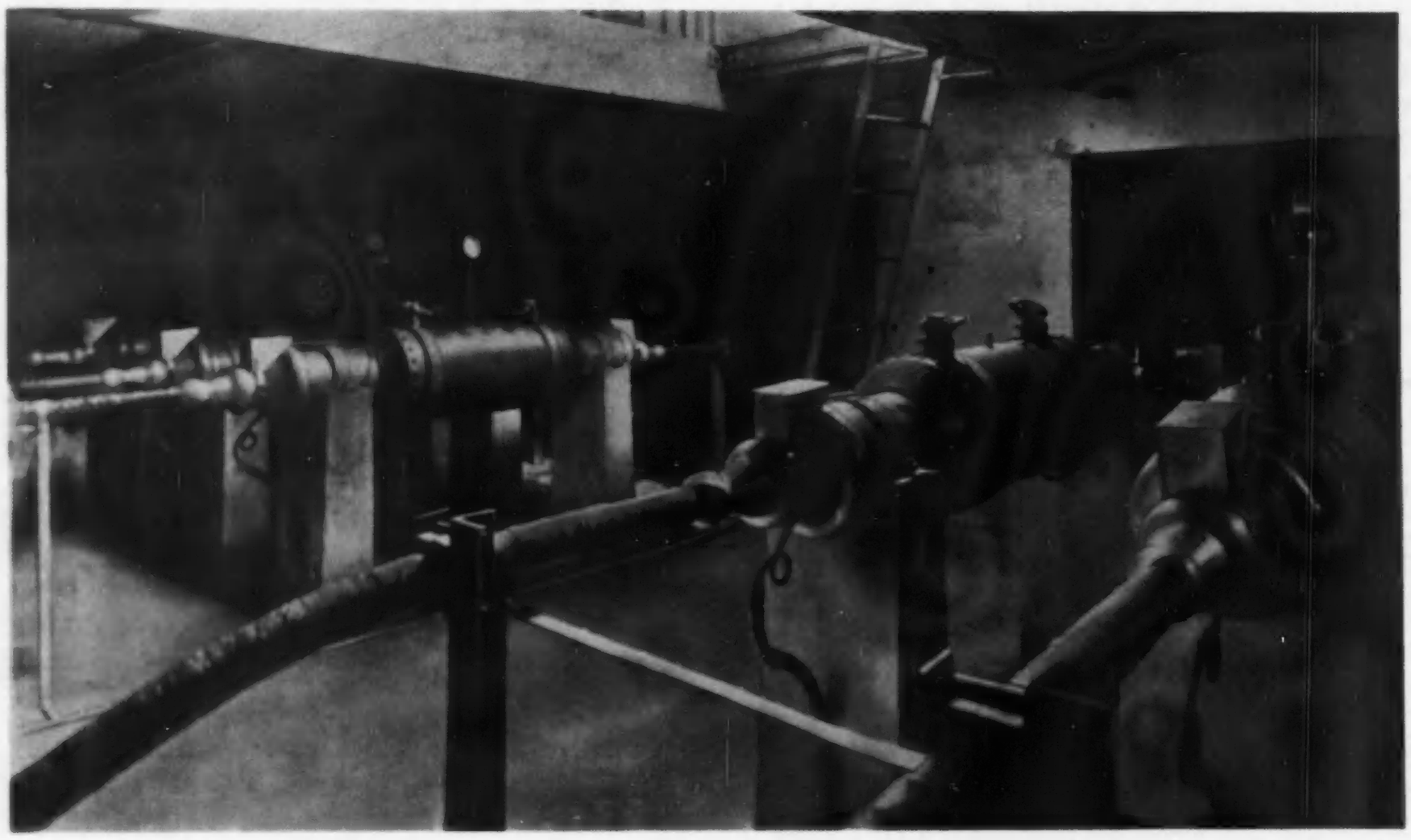


Fig. 12.—A stop-joint installation on a 66 kV oil-filled cable line.

Dried, degasified oil must also be pumped into the tanks installed at the various feeding points along the cable route in order to replace the oil lost during the various jointing operations. In this manner the correct oil pressure conditions are maintained in all parts of the installation. Specially trained oil engineers are responsible for the maintenance of the proper conditions at the feeding points, for the portable tank service and for the impregnating operations on joints and sealing ends.

A battery of pressure tanks is shown in fig. 13. This battery is used for feeding oil into one end of a 3½-mile run of oil-filled cable. The field type degasifier and pump used for refilling pressure tanks can be seen in the foreground. In fig. 14 are shown the feeding tanks required at the other end of the same line. These tanks supply six single-core cables and can be connected either all in parallel to feed the cables in parallel, or in such a way as to

feed the cables individually according to the position of the controlling valves through which the oil passes from tank to cable.

OIL RESTRICTORS.

In order to prevent excessive loss of oil due to accidental leakage in the cable system or to the opening of the cable ends during jointing operations, a device is fitted in the pipe line between each feeding tank or pressure tank and its control valve. This device is called a restrictor and is introduced for the purpose of diminishing the flow of oil from the reservoirs feeding the cable, thus limiting the loss of oil from one end of an open length of cable during laying or repairing, or from any leakage from the lead sheath that may arise from an accident to the cable.

This restricting effect cannot be produced by merely fitting a small diameter tube in the pipe connecting the reservoirs with the cable for the reason that the resistance opposed to the passage of oil is simply proportional to its flow. Thus, as soon as the leakage occurs, the flow would be abundant at first and would then rapidly diminish with the drop of pressure in the reservoir.

The restrictor consists of a series of cells, or compartments, through which the oil successively passes in such a way as to oppose a resistance to the flow so that the drop of pressure is proportional to the square of the flow of oil. The presence of a restrictor reduces to a great extent the loss of oil which may occur from a leakage. In each feeding tank position or pressure tank installation, restrictors are inserted between the accessories and each cable.

IMPREGNATION TEST OF CABLE SECTIONS.

Each section of an oil-filled cable line is terminated by a stop joint, if it is an inner section, or by a sealing end and a stop joint if it is an end section. Each section, of course, is under pressure of oil, the degree of which depends on the profile of the route and the temperature conditions at the time at which the pressure is measured. Before the section is handed over, an impregnation test is taken which includes all the cable joints and other apparatus in the section.

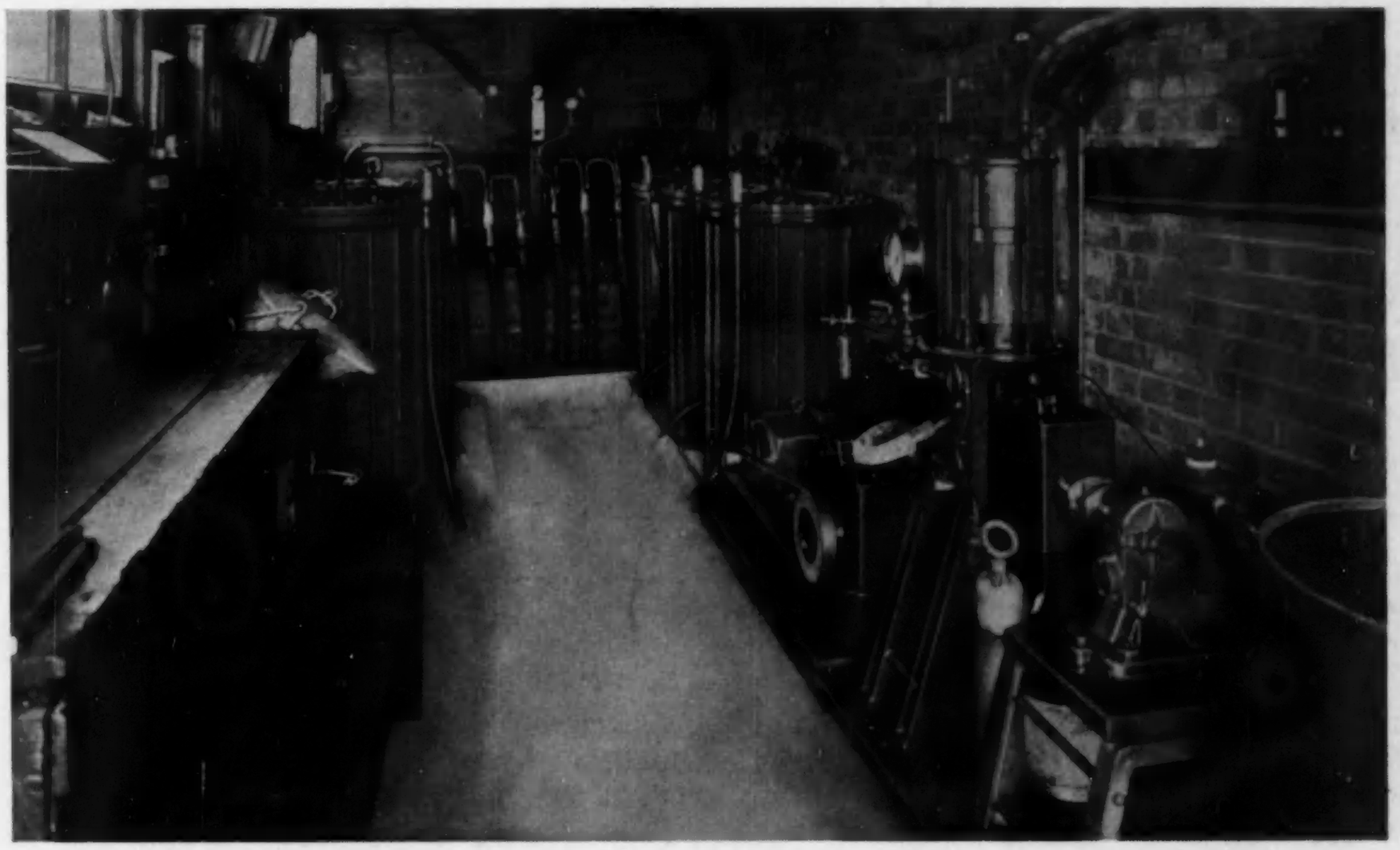


Fig. 13.—Pressure tanks used for feeding oil into a 3½-mile run of oil-filled cable.

This impregnation test is made by observing the pressure change which follows the withdrawal of a measured volume of oil when the feeding and pressure tanks are temporarily shut off. The test is similar to that made on the cable in the factory, and forms a valuable check on the efficiency of the various installation operations. The results are always better than those originally obtained with the cable at the factory, and shows that oil absorption continues for some time after the cable and joints are first made.

REGULAR INSPECTION.

In conclusion, it is pointed out that, provided a positive oil pressure is maintained on the cable system, the cable is unlikely to deteriorate. It is in this respect that oil-filled cable presents such a marked contrast to all other types of high voltage cable. It is therefore necessary to arrange for

regular inspection of feeding points to ensure that all the apparatus is in good order.

A good example illustrating the necessity of regular inspection is afforded by the 132 kV oil-filled cables installed in Chicago and New York. These have been inspected regularly since their inception 3½ years ago. In the early part of their working life some accidental oil leakages occurred and were discovered long before they became serious, thus allowing the Companies concerned to carry out the necessary repairs in an efficient manner and at the most convenient time. Sections in which oil leaks had been suspected were kept in service by the addition of oil to the tanks feeding the affected section until inspection of the joint manholes revealed the position and nature of the trouble. The necessary steps were then taken to remedy the defect. When it was found necessary to change a length of cable, the new length was pulled into an adjacent duct and all the necessary preparations made for jointing. The line was then taken out of service and the new length jointed in and restored to service within twenty-four hours. In installations where the cable is buried direct in the ground, any leakage of oil should by inspection be known to be confined to one section. By measurement of the difference in the rates of flow of oil in the three cables forming the three-phase line, it is possible to estimate the point at which leakage occurs.

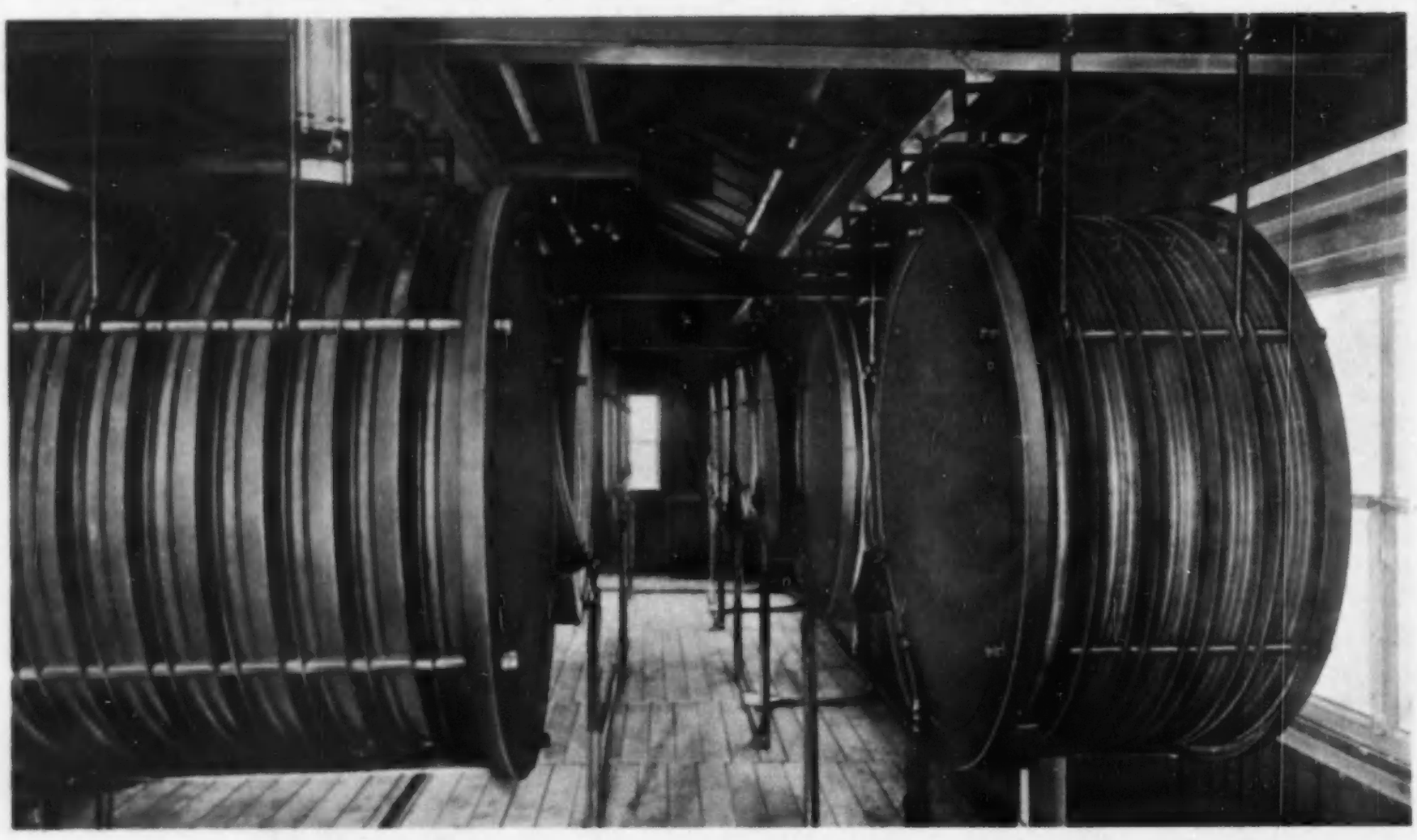


Fig. 14.—Battery of feeding tanks used for a 3½-mile run of oil-filled cable.

The care taken during manufacture, however, reduces to a minimum the risk of faults occurring in material or through workmanship, whilst the precautions adopted during installation and the mechanical protection afforded by the reinforced concrete slabs laid over the cable prevent external mechanical damage.

Transformers for New Zealand leaving Witton Works.

These seven 5,500 kVA single-phase units are for the Waitaki Power Board, N.Z., and will form two 16,500 kVA 3-phase banks interconnecting two transmission systems of 110 and 66 kV.